(2) LEVEL II

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THESIS

DETERMINING THE TRAINING EFFECTIVENESS AND COST-EFFECTIVENESS OF VISUAL FLIGHT SIMULATORS FOR MILITARY AIRCRAFT

by

George Benjamin Mayer, Jr.

June 1981

Thesis Advisor: W. H. Skierkowski

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO. AD-A104 627	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Determining the Training Effectiveness and Cost-Effectiveness of Visual Flight Simulators for Military Aircraft.		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis, June 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) George Benjamin Mayer, Jr.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE June 1981
		13. NUMBER OF PAGES 139
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Flight simulation, Cost-benefit analysis, Cost effectiveness analysis, Computer generated imagery, Training effectiveness, Model boards, Air-to-ground training, Air-to-air training, Instrument training, Cost-effectiveness models, Computer animated photographic view, Transfer of training measurement, Night carrier landing training

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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DD FORM 1473, 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

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Determining the Training Effectiveness and Cost-Effectiveness of Visual Flight Simulators for Military Aircraft

by

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Major, United States Marine Corps
B.S., University of Florida, 1976

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

The constraint on oil flow from the Middle East as a result of the 1973 war and the increased sophistication of aircraft weapons systems are two important factors which have contributed significantly to the interest in visual flight simulation as an integral part of military flight training. Costs associated with these factors, such as procurement and fuel costs, are providing pressure to the military establishment to improve their capability to provide military pilots with visual flight simulation systems which do not impair combat effectiveness or aviation safety. This thesis describes the results of flight simulation utilization by the commercial airline industry, analyzes the effectiveness realized by using flight simulators to supplement military training in different aviation environments, and outlines methodologies for measuring and improving the cost-effectiveness of the systems. Recommendations for careful study are made in areas that would improve military utilization of flight simulation.

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ACKNOWLEDGEMENT

The author wishes to express sincere appreciation to the following people who provided the much needed support that is necessary when conducting thesis research:

- Mr. Paul Bacon, United Airlines
- Dr. Dan Boger, Assistant Professor, Naval Postgraduate School
- Colonel A. Castalano, USMC, Naval Training Equipment Center
- Commander Norm Green, USN, Code N-43A, Chief of Naval Education and Training
- Mr. John Hancock, American Airlines
- Captain W. R. Jones, Delta Airlines
- Mr. George Kitchel, Vought Corporation
- Mr. Larry Lanchoney, Naval Training Equipment Center
- Major Bob Magnus, USMC, Headquarters U.S. Marine Corps
- Major Mike Moorman, USAF, 82 FTW/DOT, Williams AFB, AZ
- Dr. Stephen Osborne, Seville Research Corporation
- Commander Larry Rasmussen, USN, Air Forces Human Resources Laboratory, Williams, AFB, AZ.
- Dr. L. E. Ryan, Naval Training Equipment Center
- Lieutenant Colonel W. H. Skierkowski, USMC, Instructor, Naval Postgraduate School
- The Library Staff, Naval Postgraduate School
- My wife, Jill, and children, Bryan and Jennifer

I. INTRODUCTION

A. PURPOSE

According to LtGen. William J. White, Deputy Chief of Staff for Aviation, United States Marine Corps, the most critical issues facing Marine aviation during the 1980's will be procuring sufficient aircraft to meet the Soviet threat, retaining sufficient pilots to man the squadrons, and preserving those aircrews and airframes through safety [Ref. 1]. It is anticipated that the F/A-18 will be introduced to the fighter community in 1984 and the AV-8B will reach the attack squadrons in 1986. The procurement of these new high performance, sophisticated aircraft supports the issue of meeting the threat; however, pilot retention and aviation safety are two areas where continuous studies are being performed to formulate answers that will satisfy the Department of Defense goals of: (1) development of better pilots and aircrew members; (2) maintenance and improvement in combat readiness; (3) reduction of training and operating costs; and (4) conservation of scarce resources such as energy, weapons, and ammunition [Ref. 2].

Constraints such as procurement costs, fuel costs, risks of flying, ecology, and training effectiveness interject additional problems in the search for answers to the issues.

An area of study that is being strongly considered to provide some relief from the constraints is military use of flight simulators.

The world's military forces will spend almost $10 billion by 1987 on development and procurement of all types of simulators and trainers. The Navy will allocate $1.7 billion for flight simulators and trainers. Major Navy flight simulator programs include the AV-8B estimated at $52 million and the F/A-18 with a projected investment of $172 million [Ref. 3]. The simulators will be state-of-the-art incorporating such characteristics as computer generated imagery (CGI) and six degrees of freedom motion systems to provide the pilot with the most realistic simulation possible, resulting in more effective training. An additional powerful side effect of these simulator procurements is the savings they represent in men, fuel, weapons, and supply support resulting in a coefficient of resource savings. The value of this coefficient has been estimated to vary between 5 and 100, depending on the type of military mission being trained in the simulator [Ref. 4].

The purpose of this thesis is to determine whether visual flight simulators for military aircraft are cost effective. A secondary purpose is to gather data supporting the training value of visual flight simulation and its impact on cost effectiveness.

B. RESEARCH METHODOLOGY

Information gathering for this thesis includes library research, phone conversations with personnel from Headquarters Marine Corps, Naval Air Systems Command, Naval Training Equipment Center, and on-site visits to a major airline Flight Training Center, and the Human Resources Laboratory, Williams AFB, Arizona, to conduct interviews with persons involved in both cost and training effectiveness of visual flight simulators.

C. THESIS ORGANIZATION

Section II provides a background for flight simulation including historical development, a description of simulation methodology such as model boards, computer animated photographic terrain view (CAPTV), and CGI, and a brief description of three tactical flight simulators, two of which are used by the Navy and one by the Air Force. Section III examines flight simulator utilization within commercial aviation. Section IV presents the training effectiveness of military flight simulators to include methods of measurement, analysis of training data, and characteristics of the flight simulator program necessary to support positive training effectiveness. Section V will examine the cost effectiveness of flight simulation, and Section VI will include the author's conclusions and recommendations.

II. FLIGHT SIMULATION - AN OVERVIEW

A. HISTORICAL DEVELOPMENT OF FLIGHT SIMULATION

The historical development of flight simulation seems to be as innovative as the airplane itself. The motivational requirement for inventiveness was stimulated by the hazards of flying, the skill required to pilot the airplane, and the need for a training aid to supplement pilot instruction. The earliest devices appear to have been devised around 1910 using actual aircraft, some of which were proposed to be moved at speed in the air supported by balloons and overhead gantries. A training device which came to be known as the "penguin" was also developed during this time period. It was a stubbed-winged aircraft capable of moving across large open spaces but incapable of leaving the ground [Ref. 5].

Prior to World War I, special training apparatuses, not based upon actual aircraft, were being developed to meet specific needs of pilot training. For example, small aircraft-like devices that were mounted on pivoted universal joints were used to show pilots the effect of prevailing winds on aerodynamic control surfaces. During the war, research attempts were made to use simulators for aircrew training. One such research attempt was a piece of equipment, produced in France in 1917, which used an aircraft fuselage based on

a pivotal mount and incorporated compressed air which produced variations of response and aerodynamic feel with variances in speed [Ref. 6].

In 1924, two English research workers, Reid and Burton, evaluated the importance of full cockpit simulation by measuring responses of pilots in a modified aircraft fuselage with functioning displays and controls. It was concluded that devices which required pilots to make responses on the ground to those made while airborne could be used to: (1) test the pilot's ability to fly and land successfully; (2) assess the rate of acquisition of flying skills; (3) train pilots on those particular motor skills necessary for aircraft controllability; and (4) classify subjects for different forms of flying service [Ref. 7].

The year 1929 proved to be a "banner year" in flight simulator development. Roeder, a German inventor, proposed an apparatus for instruction in the navigation of vehicles in free space utilizing a hydraulic system which would reproduce the physical movement of an airship not unlike the motion systems of some present-day simulators. The first Link Trainer was also completed in 1929 by Edwin Link in the basement of his father's piano and organ factory in Binghamton, New York [Ref. 8]. The drive for the instruments and motion system of the trainer used the pneumatic technology of organ building. The Second World War provided the necessary impetus for the development of the Link as a mass produced ground trainer.

After the war, development of computer technology accelerated the design of flight simulators. First in analog and now in digital form, the modern flight simulator uses sophisticated computing techniques to animate full scale representations of the operational environment experienced by the pilot during flight.

B. VISUAL FLIGHT SIMULATION METHODOLOGY

1. Model Boards

The first method described by the author for visual flight simulation is the model board. As a reference, the system described is used on the 2F-87 Operational Flight Trainer (OFT) for the P-3 aircraft.

The model board provides the pilot with a realistic view of external scenery enabling flight crews to perform visual take-off, approach, landing, and low-altitude maneuvering procedures under day, dusk, or night conditions. The instructor also has the capability of selectively varying visibility and cloud effects.

The main system includes a rigid three dimensional model of an airfield located in the midst of a landscape scaled at 2000:1, a closed circuit color television system, and a gantry-mounted camera which moves over the model board to simulate height and movement over the ground in response to simulator control inputs. A special optical probe, attached in front of the camera, contains servo-controlled optical

systems which simulate the in-flight pitch, bank, and heading changes [Ref. 9]. A camera trip system is provided to prevent damage to the optical probe due to contact with the model surface. Using a pressure-sensitive switch for activation allows the camera and probe to retract should it come in contact with the model.

Three drive systems, driven by signals originating in the OFT, control movement of the camera along the longitudinal, lateral, and height axes as illustrated in Figure II-1. Total travel of the longitudinal (X axis) and lateral (Y axis) drive systems are approximately 37 feet and 12 feet respectively and are equivalent to a maneuvering area of 12 by 4 nautical miles over the 2000:1 scale model board. The maximum travel in the vertical system (Z axis) is 12 inches, which is equivalent to the height of 2000 feet [Ref. 10].

Detail of the terrain is provided by a pitch mirror which is set at an angle of 45 degrees to the optical axis when the OFT is in level flight. The angle of the mirror can be changed $\pm$ 12.25 degrees, simulating aircraft movement. Outside of this range an in-cloud picture is presented to the pilot. The effects of bank angle are simulated by using a dove prism in the optical probe, and the nose section, including the pitch mirror, is rotated about the optical path to simulate heading change. Focal distance, from the pilot's view, is continuously updated, resulting in a signal being applied to the focus drive system. The optical system, as described, is depicted in Figure II-2.

FIGURE II-1 CAMERA MOTION SYSTEMS
(SOURCE: P-3C VISUAL SYSTEM FOR DEVICE 2F87 MAINTENANCE MANUAL)

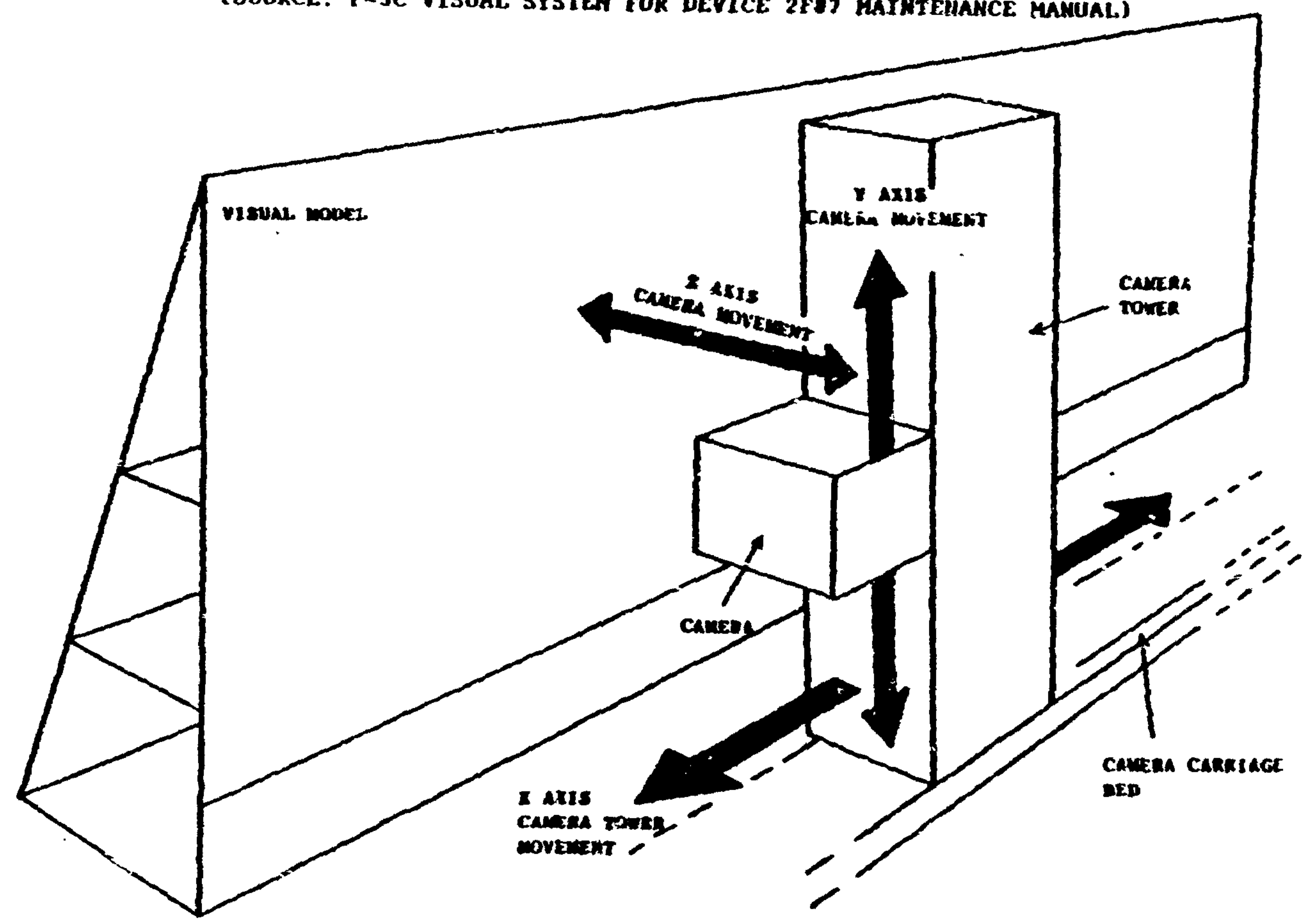
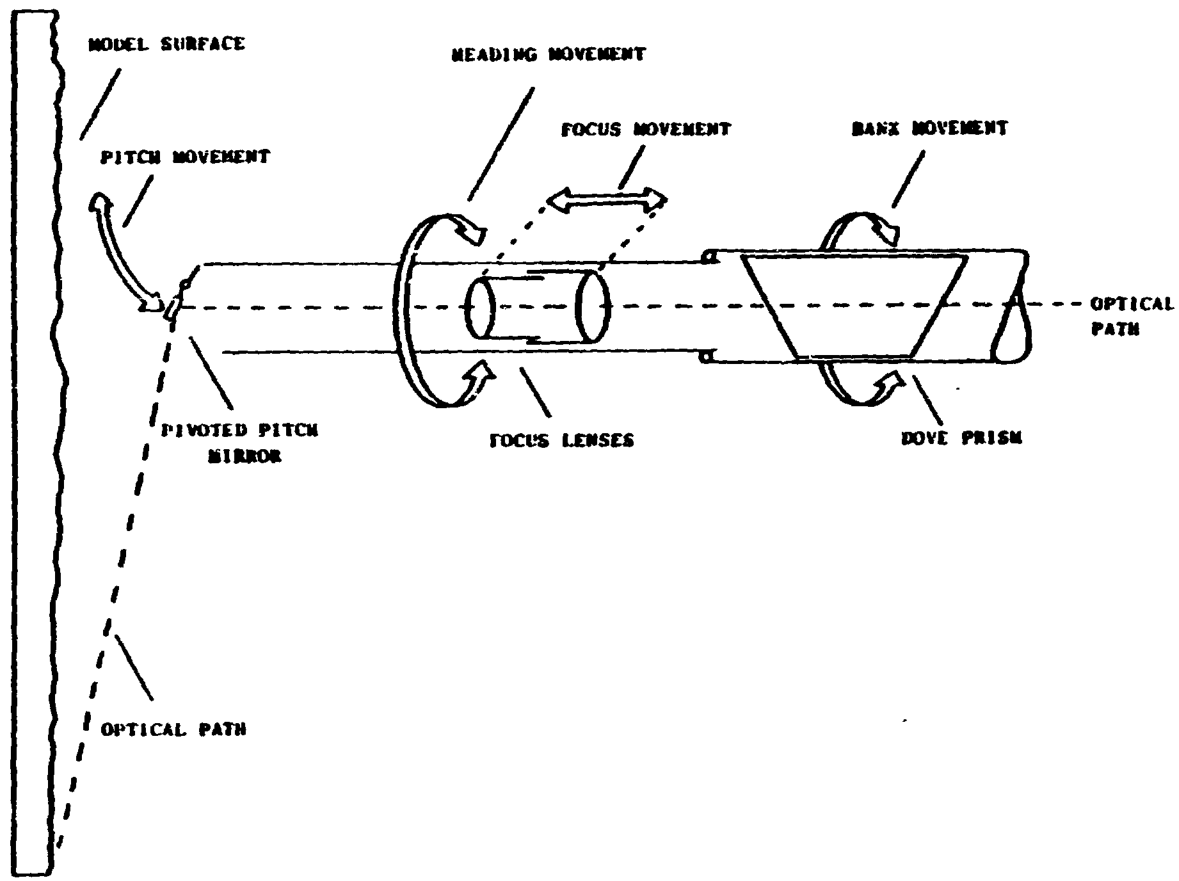


FIGURE II-2 PROBE OPTICAL SYSTEMS
(SOURCE: P3-C VISUAL SYSTEM FOR DEVICE 2F87 MAINTENANCE MANUAL)



The model board is illuminated by a bank of 850 eight foot (244 cm) fluorescent tubes located approximately seven feet from the model surface [Ref. 11]. There is also lighting on the camera tower to eliminate shadows cast by the tower structure which moves on a track between the model board and the lighting bank. Control of the light banks creates the simulation of day, dusk, and night conditions. Small prisms illuminated from behind the model are used to simulate the airfield lighting system, as shown in Figure II-3. Approach, strobe, visual approach slope indicators, touch-down zone lighting, runway end identification lights, runway, and taxiway lighting are included within this system. Realism of the night scene is enhanced even more by lighting elements incorporated into the terrain around the airfield simulating lights from a city.

Figure II-4 illustrates the positioning of the projector, mirrors, and screen necessary for the display system. The high brightness of the display allows the level of cockpit illumination to be consistent with day, dusk, or night conditions. The image is projected from a color television projector mounted on top of the simulator fuselage through a mirror system onto a back projection screen. The pilot views the visual scene by means of a large collimating mirror positioned ahead of the cockpit.

FIGURE II-3 AIRFIELD AND TERRAIN LIGHTING
(SOURCE: P-3C VISUAL SYSTEM FOR DEVICE 2F87 MAINTENANCE MANUAL)

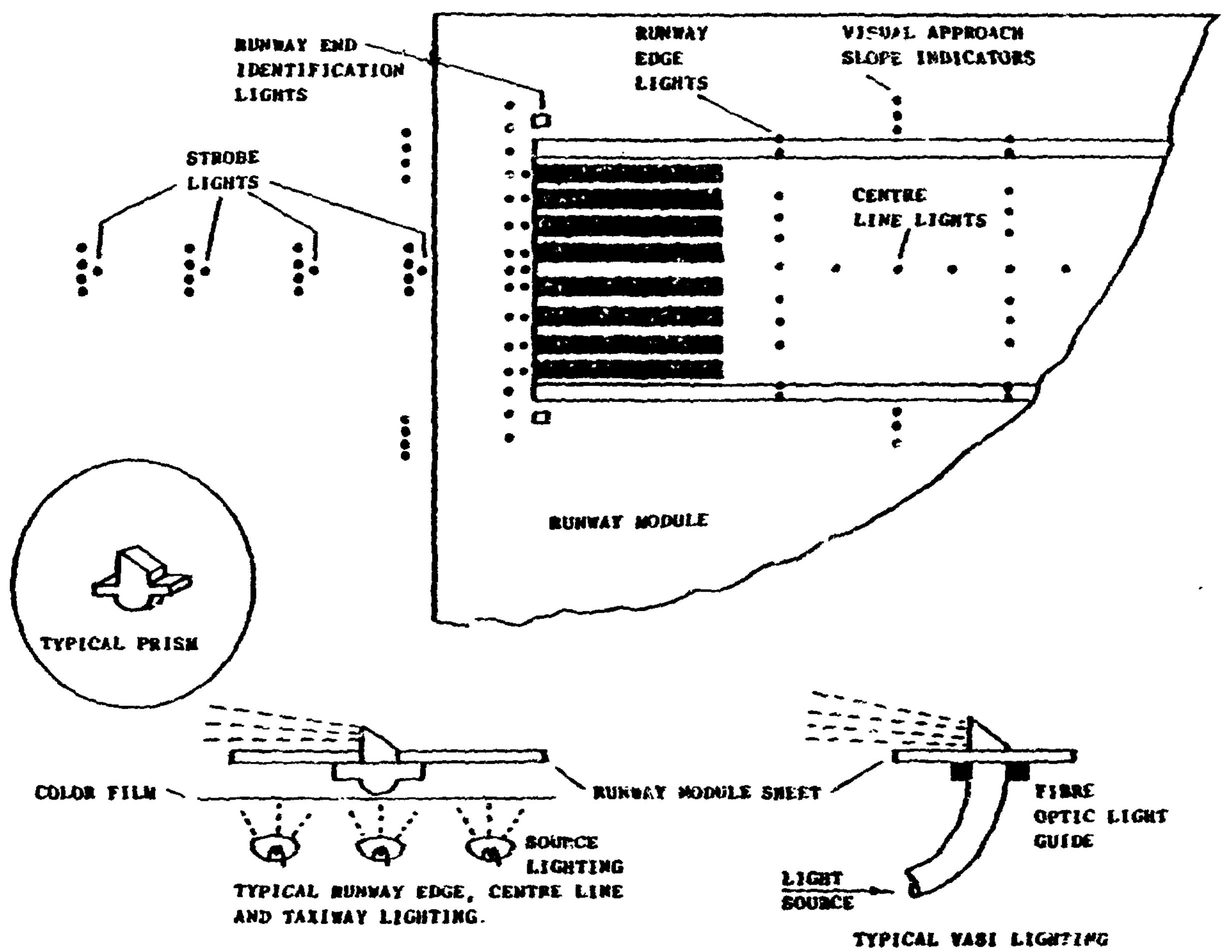
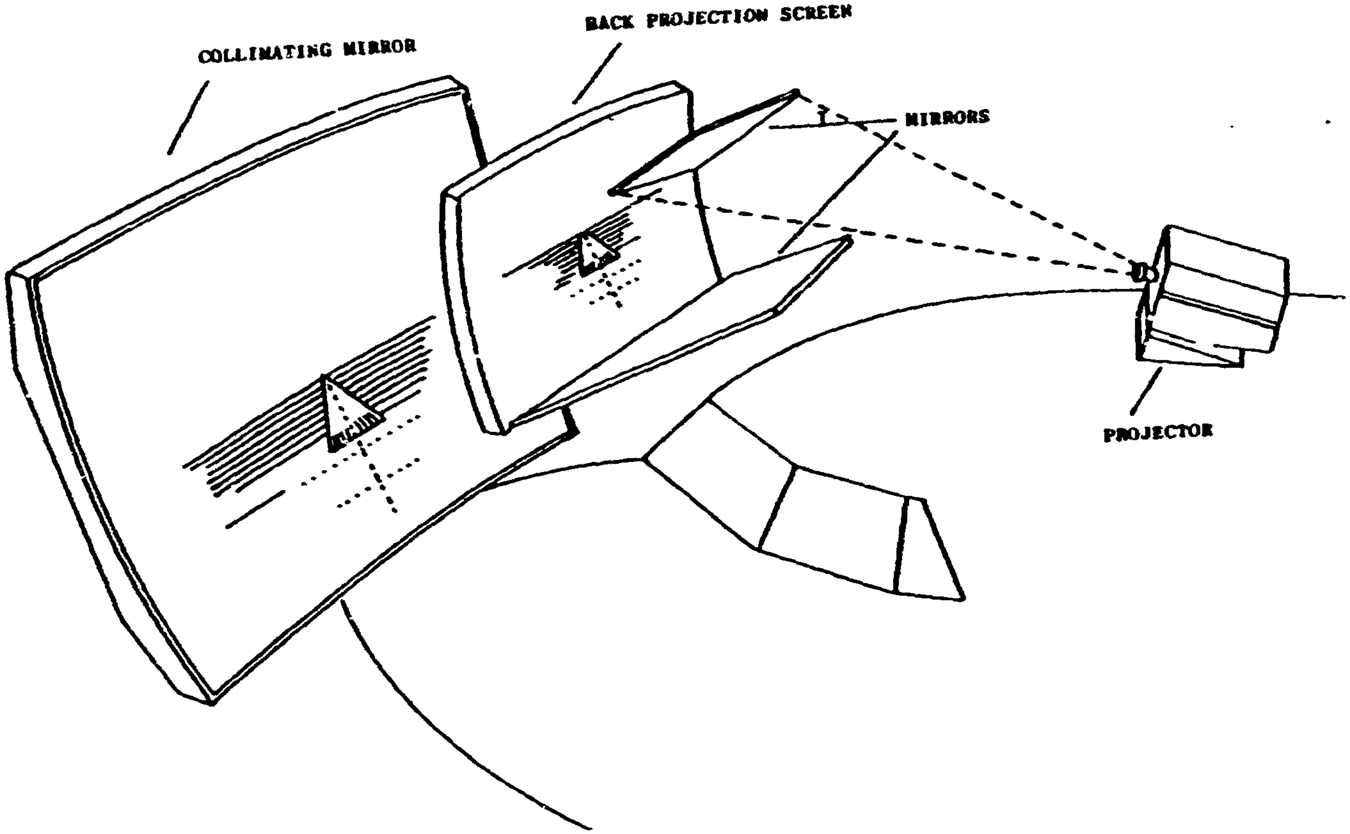


FIGURE II-4 DISPLAY SYSTEM
(SOURCE: P3-C VISUAL SYSTEM FOR DEVICE 2F87 MAINTENANCE MANUAL)



2. Computer Generated Imagery (CGI)

The Computer Generated Imagery system consists of a numerically stored environment model, a computation system for generation of display video from the numerically stored environment, and display electronics for driving the cathode ray tube (CRT) display system [Ref. 12]. This system is presently used by the Air Force Human Resources Laboratory (AFHRL) on their Advanced Simulator for Pilot Training (ASPT).

Maneuverability by the pilot through the control system of the simulated aircraft is unlimited. The scenery changes are generated in response to the pilot's viewpoint position and attitude in real time with generation of a complete new visual scene displayed each 1/30 of a second [Ref. 13].

The physical environment, which consists of a flat surface representing the surface of the earth and three-dimensional objects representing solid figures, is numerically described in three-dimensional vector space.

When the system is in the on-line operational mode, it accomplishes its real-time scene generation task in a serial manner. Data that is necessary for scene computation is requested from the computer subsystem each 1/30 of a second and the corresponding scene is completely displayed within 1/10 of a second of receiving new scene data [Ref. 14].

Three time phases are used for processing the display data. The phases are referred to as Frames I, II, and III.

While Frame III is producing the video signal that is being observed by the pilot, Frame II is preparing information for the picture to be used in the next television frame period, and Frame I is working on the most recently requested data which is driven by the pilot's viewpoint position and attitude [Ref. 15].

Visual scene development using a CGI system has certain primary capabilities including exact perspectiveness, real-time display of moving objects, quick visual environment change or modification, unlimited rate of maneuverability, and a large area of flight coverage [Ref. 16]. The imagery, as viewed by the pilot, consists of surface patterns or objects formed by planes of different brightness levels bounded by straight lines or "edges." A system with a finite edge generation capability results in a stylistic presentation rather than according to nature. As a rule, the degree of stylization is inversely proportional to the edge generation capability of the system since scenes in the real world are not constrained to representation by straight lines or edges [Ref. 17]. To improve image quality, two techniques, edge smoothing and continuous shading of surfaces, are employed. The edge smoothing feature provides a gradual transition across an edge while the continuous shading of surfaces capability permits the generation of imagery representing curved surfaces [Ref. 18]. The present system has the capability

of generating 2500 edges with 2000 being displayed at any one time [Ref. 19].

Using the serial method of visual scene generation, the system, up to this point, has been storing, retrieving, and transforming edge format information. The next step in the process is to convert edge format into digital scan line format allowing the brightness level of each part of the scan line to be in digital form. This scan line information is then converted into a video signal by a high-speed digital-to-analog converter. This signal is then distributed to the fourteen display planes for viewing by the pilot, all in less than 100 milliseconds [Ref. 20]. The system, as it presently exists for the Advanced Simulator for Pilot Training (ASPT), has two cockpits, each with seven video display planes. The planes are juxtapositioned about one viewing point with overlapping visual information. The system has the capability of providing a minimum of 7.2 degrees overlap of visual information on the borders of the seven display planes. When one edge is displayed in two or more adjacent channels, the system will generate the signal such that this edge has less than one degree discontinuity across the display joint [Ref. 21].

Difficult maneuvers to visually simulate, which include overhead pattern and landing, formation flight, and aerobatics, can be accomplished using CGI. For example, the pilot can fly over the runway at 1000 feet, then make a 180 degree level turn to the downwind and fly the appropriate

landing pattern to touchdown. Throughout this maneuver, the pilot uses computer generated visual cues that are being projected on the seven display planes to determine attitude and position with respect to the touchdown point. Precise aerobatic maneuvers can be accomplished because the pilot is able to look directly overhead and out both sides of the cockpit for aircraft control and performance assessment. During formation flying, the pilot uses visual cues from the lead aircraft to maintain a satisfactory wing position.

Reliability of the CGI system has a design goal in terms of mean-time-between-failures of 150 hours [Ref. 22]. The system is also designed to have a minimum accumulated operating life of 30,000 hours and a maintainability requirement that maintenance man-hours, comprised of corrective and preventive maintenance, calibrations, and servicing, will not exceed 20 percent of the accumulated operating time [Ref. 23].

There are limitations to CGI predominantly in the area of image content and detail; however, with the advent of present technology, the system provides a more complete visual simulation in terms of perspective, field of view, and unprogrammed flight conditions [Ref. 24]. In a paper presented to the National Aerospace meeting, Mr. G. V. McCulloch, United Airlines Flight Training Center, stated:

> United Airlines believes that computer generated imaging is the visual simulation technique offering the greatest promise of making total airplane simulation possible. [Ref. 25].

3. Computer Animated Photographic Terrain View (CAPTV)

A third method by which visual scenes can be produced for flight simulation is Computer Animated Photographic Terrain View (CAPTV). This system is under development and being considered for the Navy's new jet aircraft training program (VTX(TS)). The process originates by having an aircraft with a camera mounted underneath the fuselage fly over a "gaming area" such as an aircraft carrier, runway, or target at different altitudes, recording the scenes on motion picture film. The camera uses seven lens systems simultaneously capturing scenes of 360 degrees in azimuth and up to 10 degrees above the horizon. The photographs are processed through a flying spot scanner, color encoded, and recorded on a video disc. The video disc units have the capability of recording 400 high fidelity color photographs per disc surface.

When the visual scenes are to be used for flight simulations, the discs are read optically by laser, that is, an electronic digital picture processor (DPP) accesses photographs from the disc and interpolates for infinite eyepoints. The DPP has a large digital memory which holds the last read scene of interest and then assembles the scene as it is accessed from the disc.

Since the camera mounted on the aircraft only covers the earth and 10 degrees above the horizon, computer generated imagery provides the sky simulation and can also be used for insetting such special effects as moving targets.

After the video special effects have been inserted, the image can be displayed using either a dome projection or cathode ray tubes. Because the visual scenes are actual photographs of the terrain and objects of interest, CAPTV can provide highly-detailed information, accurate depth perception, and real-world scenery texture within a large field of view [Ref. 26].

C. A DESCRIPTION OF MILITARY FLIGHT SIMULATORS

1. A-7E Night Carrier Landing Trainer, Device 2F-103

The Night Carrier Landing Trainer (NCLT) is utilized to simulate an A-7E aircraft flying a night aircraft carrier approach and landing. The system is composed of a simulated A-7E cockpit, a visual display system, a 3 degree-of-freedom motion system, instructor console, digital computer, and related hydraulic and electrical supplies [Ref. 27]. The visual scene is displayed on a single cathode ray tube which is positioned in front of the cockpit, providing the pilot with a 40 degree horizontal and 30 degree vertical colored picture of the deck lighting and visual landing aids such as the Fresnel Lens Optical Landing System (FLOLS), which is properly positioned in relation to the deck edge, the runway lights, and vertical drop lights, all of which are used to form a basic "night" landing picture. The computer generates a two dimensional perspective view of the carrier lights and updates the spatial placement as a function of closing range

to touchdown and high/low or left/right approach positions dictated by real-time pilot control inputs [Ref. 28].

Through interface with the instructor console, the Landing Signal Officer (LSO) can monitor the pilot's performance. The LSO can also vary the degree of difficulty of each approach by selecting different environmental characteristics such as a rough sea state or high wind conditions across the aircraft carrier deck. Fourteen aircraft emergencies can also be programmed during any approach [Ref. 29].

In order to improve upon debriefing procedures, the LSO can obtain records from an X-Y plotter which shows altitude and lateral error deviations from the desired glideslope and line up. In addition to this recording capability, the system can replay the last minute of final approach and also "freeze" the display so that the LSO can provide instructional advice at the point in time where the pilot commits the error. In addition, information such as angle-of-attack (AOA) control, power control, pitch control, and tailhook-to-ramp clearance can also be displayed to both the pilot and instructor. If desired, a hard copy of these results can be obtained from the printer.

The NCLT provides the pilot with complete freedom to fly the aircraft and realistic aircraft sounds throughout the flight. Carrier arrestment is simulated by stopping the CRT display. The device also has the capability of simulating landing and missing the arresting wires with the aircraft

tailhook, touch-and-goes, ramp strikes, and allows the pilot to re-enter the final approach pattern after each missed landing [Ref. 30].

2. A-7E Weapons System Trainer, Device 2F-111

This system includes an A-7E cockpit mounted on a six degree-of-freedom motion platform, digital computers, a digital radar landmass system, interface equipment, and instructor's console. The trainer features flight validated systems to include departure from flight, aircraft spin and recovery characteristics, utilization of CRT displays for instructor information, integration of the navigational computer with other systems, and performance measurement capability [Ref. 31].

Simulation of the aircraft is very precise with the system including all modes of engine and fuel system operation, hydraulic and electrical systems, flying qualities, and performance characteristics.

For tactical instruction, the system includes simulation of weapon delivery, loading, arming, safeing, and ordnance release. The instructor has the capability of simulating any weapons loading configuration. In addition, the trainer can simulate signals that are emitted when enemy weapons systems have a radar-lock-on such as a surface-to-air missile (SAM) allowing the pilot to practice using electronic countermeasure systems and also to perform appropriate evasive maneuvers.

The system also has a "freeze" capability allowing the instructor to completely stop all systems for debriefing and analysis and then move to another geographical location to continue the training situation. There is a data base map within the system which depicts a 1250 x 1250 nautical mile area of either the western or eastern United States [Ref. 32].

The instructor has the ability to enter eighty malfunctions into the system, increasing the level of difficulty for the pilot-under-training. Four CRT displays allow the instructor to monitor the status of the training mission and the proficiency of the pilot in accomplishing the mission. Included within the displays are a repeat of cockpit switch positions, instrument panel indications, the capability to monitor sequential actions by the pilot for a given procedure, and information relating to the position and orientation of the aircraft [Ref. 33].

3. Advanced Simulator for Pilot Training (ASPT)

The Advanced Simulator for Pilot Training (ASPT) is used primarily in the research area with formally stated objectives of the program being: (1) to enhance pilot training within the Air Force through the application of recent technological advances in simulation; (2) to demonstrate the maximum effective utilization of simulators in Air Force pilot training; and (3) to define the future generation of ground training equipment and simulators [Ref. 34].

The system is comprised of three major components: the basic simulators, the visual displays, and the computer image generator [Ref. 35]. The visual display and computer image generating systems for the ASPT have been described in a preceding section, therefore the basic simulator will be described at this point.

The ASPT is presently configured with the F-16 and the A-10 cockpits enclosed within the seven-channel visual display systems. The realistic appearances of the cockpits are provided by the utilization of actual aircraft parts, and the cockpits include faithful reproductions of in-cockpit sights, sounds, and aerodynamic control feel to the maximum extent allowable within the state-of-the-art in simulation.

The motion system provides the on-set acceleration cues along and about the three aircraft axes. The motion platform is supported by six active hydraulic actuators with six passive safety actuators providing complete mechanical redundancy in case of system failure. The sixty-inch stroke system is essentially a hydraulic position servo that is driven by commanded actuator lengths computed by the motion system mathematical model [Ref. 36].

The ASPT also has provisions for introducing several levels of difficulty and complexity within any given task. These variables are accomplished by restricting any combination of the six degrees-of-freedom motion system, varying aircraft response to control movements, inserting system

malfunctions, or introducing environmental factors such as temperature changes, turbulence, and wind velocity.

The ASPT has the capability to "freeze" the simulated visual scene, reinitialize to a point in space, automatic demonstration, provide the student with knowledge of the results, and playback of a particular maneuver.

Unlike other flight simulation systems described in this section, the ASPT, through Computer Generated Imagery, can change the training environment almost instantaneously. This author had the opportunity to "fly" the A-10 ASPT during a recent visit to the Human Resources Laboratory, Williams AFB, Arizona. During the sixty minute training period, the author flew in four different environments to include aircraft carrier approaches and landings, formation flying with a simulated A-10 aircraft, air-to-air refueling using a simulated KC-135 tanker, and air-to-ground ordnance delivery in a hostile environment. While in the last three environments, the computer demonstrated a "perfect" maneuver involving all instrument readings and visual scenes of the total simulator system. When first shown the CGI environment, the author was concerned with the lack of realism. However, after becoming involved in performing the required tasks such as flying the approach to the aircraft carrier, the realistic aspect of the visual scene became secondary in importance while the correct performance of the maneuver was of primary interest.

D. SUMMARY

Part A of this section outlined the historical development of flight simulation from the earliest devices around 1910 using actual aircraft to the modern flight simulator which uses sophisticated computing techniques to animate full scale representations of the operational environment experienced by the pilot during flight. Part B described different methods being utilized today to provide visual flight simulation. The methods included model boards, computer generated imagery (CGI), and computer animated photographic terrain view (CAPTV). Part C presented a description of three military flight simulators including the A-7E Night Carrier Landing Trainer, the A-7E Weapons System Trainer, and the Advanced Simulator for Pilot Training being used by the Air Force for visual flight simulation research.

III. FLIGHT SIMULATOR UTILIZATION IN THE COMMERCIAL AVIATION INDUSTRY

A. GENERAL

The use of flight simulators to provide initial and recurrent training for flight crews of commercial airline companies has increased rapidly since World War II. The airline companies saw flight simulator utilization as an opportunity to reduce the costs associated with training their Captains, First Officers, and Flight Engineers. Improvements in flight simulation hardware, supported by more complete performance data from aircraft flight tests, and fostered by a more permissive Federal Aviation Administration (FAA) regulatory environment, have moved the air transport industry closer to an ultimate goal of total flight training through simulation [Ref. 37].

The impetus to use flight simulators has been provided by three primary considerations, namely, safety, simulator quality, and energy conservation. Within the safety regime, pilots are able to practice unique maneuvers such as power loss after takeoff commital speed, and limited power on final approach to landing. Simulator training is especially imperative for Flight Engineers, because it permits shut-down of electrical or hydraulic systems without exposing the aircraft to undue hazards. An additional effective utilization of

simulators to improve safety conditions would be using the devices to reconstruct events as they occurred during flight. To illustrate, on May 25, 1979, an American Airlines DC-10 crashed after losing the left engine on takeoff from Chicago's O'Hare Airport. Technicians took data from the flight recorder of the crashed aircraft and translated the information into a computer to be used with a DC-10 simulator to try to determine why the pilot could not control the left roll, and if any combination of aerodynamic control inputs or throttle positions of the remaining operable engines could have prevented the accident [Ref. 38].

New simulation equipment that is being procured by the major airline carriers is inherently capable of fulfilling FAA advanced simulation requirements. State-of-the-art simulators use computer generated imagery and six degrees-of-freedom motion systems. There are normally four visual screens positioned in front of and on the left side of the Captain and in front of and on the right side of the First Officer. These side screens allow the pilots to practice circling approaches instead of being restricted to straight-in approaches to landing. FAA requirements will be explained in detail in a subsequent part of this chapter.

During the early stages of flight simulator development aircraft costs incurred to practice procedures and build practical experience were less expensive than investments in peripheral training equipment. As a result of escalating fuel

costs and increased technology,,this trend has reversed itself. The Boeing Corporation determined that visual simulators have trimmed 12 of the 18 flight hours formerly scheduled for each pilot transitioning to one of their jet aircraft. As an example, the cost associated with transition training in a Boeing 727 is $1400 per flight hour in the aircraft versus $280 per flight hour in the simulator [Ref. 39]. Without the simulator the training cost would be $1400 per hour x 18 hours = $25,200. With the simulator/aircraft combination the training cost would be $1400 per hour x 6 hours plus $280 per hour x 12 hours = $11,760. This results in a savings of $13,440 for each pilot trained. Data obtained from a major airline company showed that their short-haul aircraft (500 nautical miles between landings) cost $1400 per flight hour while the simulator cost was $250 per hour, and their long-haul aircraft (in excess of 1100 nautical miles between landings) cost $5600 per flight hour while the simulator was $300 per hour. For qualification as Captain in the short-haul aircraft, a pilot would require approximately 12 hours in the aircraft only ($16,800) or 16 hours in the simulator plus three hours in the aircraft ($8,200). In the long-haul aircraft, qualifications would require approximately 12 hours in the aircraft only ($67,200), or 15 hours in the simulator plus two hours in the aircraft ($15,700). Based on 822 crew qualifications per year in the short-haul aircraft and 411 qualifications per year in the long-haul aircraft, this major airline

company recognized potential annual cost-savings associated with training of $7,069,200 and $21,166,500 respectively in 1980 [Ref. 40].

Flight simulation technology has progressed from a simple fixed base of a single place cockpit to a device capable of immersing a pilot and his crew in a very realistic and typical flight situation. Detailed environmental situations such as communication with the ground crew during "pushback," reaction of the aircraft to wind shear, any level of aircraft system malfunction, ground effect, and braking deceleration on landing rollout can be realistically simulated with state-of-the-art technology [Ref. 41]. American Airlines has conducted at least eighty requalifications of pilots who had been away from line duty for periods of ninety days to two years with complete retraining in a simulator under an FAA exemption and with no non-revenue flight time. American also conducted upgrade studies taking First Officers who were current within the past two years as pilots of airplanes of the same type and upgrading to Captain with no aircraft non-revenue time [Ref. 42].

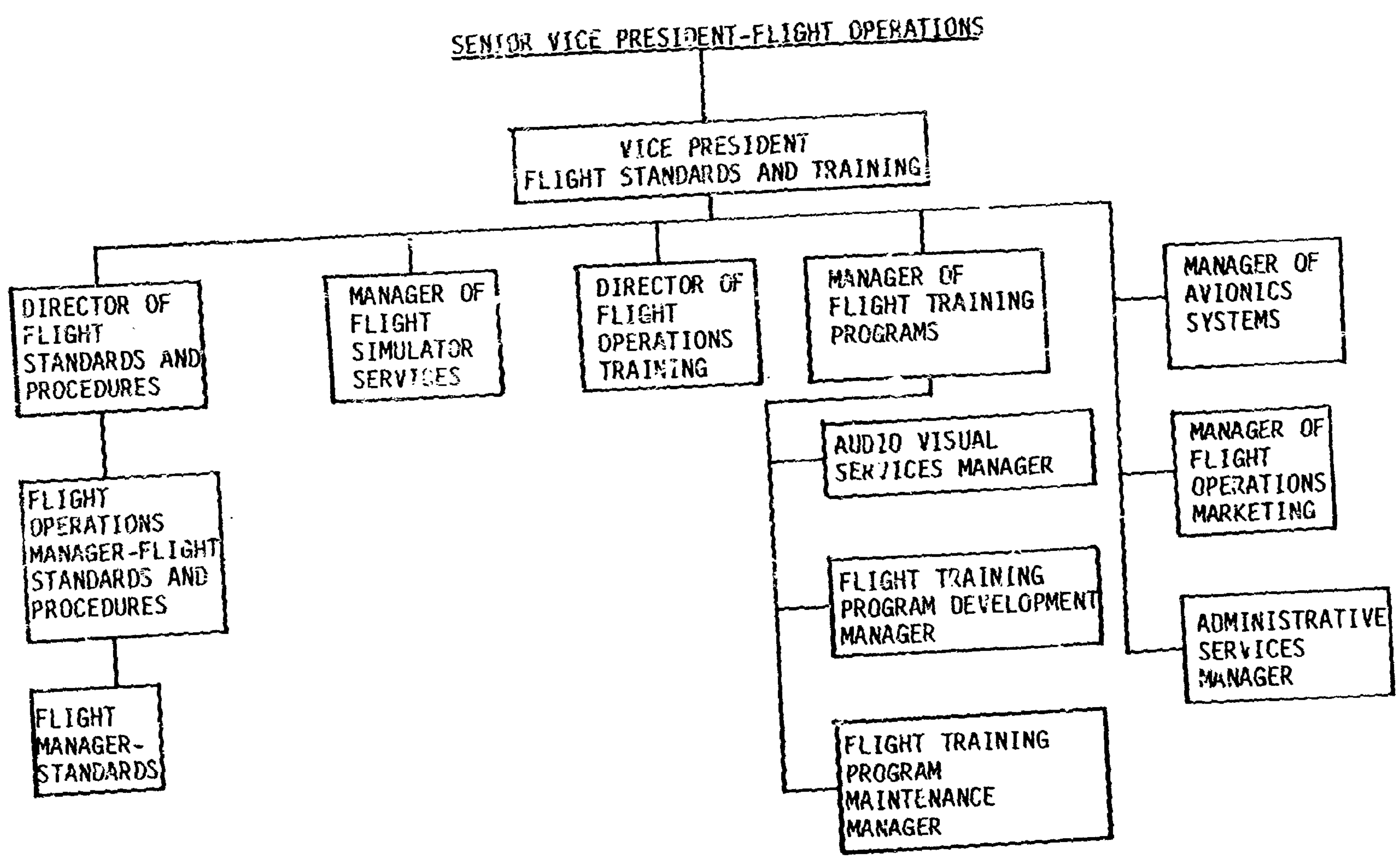
Commercial airlines use of flight simulators is a multi-million dollar business; therefore, a tremendous effort is put forth in organizing and operating the training centers which utilize the simulators. The next part of Section III will describe such a training center.

B. THE FLIGHT TRAINING CENTER CONCEPT

Extensive research by this author has shown that major airlines have tended to centralize their training facilities in order to take advantage of economies of scale and to improve standardized operating procedures. In 1966, as a result of a study completed by a private consulting firm, American Airlines centralized their training program in the Dallas-Fort Worth area. This change had been precipitated by the fact that two fatal training accidents had recently occurred with a primary cause being a difficulty in maintaining standardization, since at that time American had training facilities in New York, Chicago, Los Angeles, and Dallas-Fort Worth. The major complex was completed in 1970 and trains approximately 4000 flight crewmen annually through any of 75 different types of flight and ground school courses covering initial, refresher, upgrade, and transition training [Ref. 43].

Figure III-1 depicts an organization chart for a major airline flight training center. It is readily apparent that the training center is a very large organization requiring a tremendous amount of coordination between major departments to ensure that operations are both effective and efficient. The Standards and Procedures Department performs all the necessary flight checks, both within the simulator and the aircraft, in order to ensure that the flight crews perform the procedures correctly. Flight Simulator Services attest to the fidelity of the flight simulators, perform necessary

FIGURE III-1
ORGANIZATION CHART FOR FLIGHT TRAINING CENTER



system changes, and ensure all systems are operating within FAA specifications. The Director of Flight Operations coordinates the input and training of all the crews ensuring that an individual's program is progressing according to the appropriate syllabus. The Manager of Flight Training Programs maintains the present training syllabus and develops new techniques for improving classroom and other media instruction. Finally, the Manager of Avionics is responsible for the maintenance effort associated with maintaining the simulators and other training devices.

Two major contributions to the success of the flight training center concept have been the instructor staff and up-to-date training systems and techniques for using these systems. The instructors are professionals with extensive backgrounds in classroom teaching in addition to considerable flight experience, averaging 15,000 to 20,000 flight hours. Training techniques, such as the concept of individualized training, has received much emphasis. This type of training permits each student to proceed at his own best learning rate. Subjects, such as aircraft systems, are divided into study units. Each study unit is intended to teach and test, with testing being accomplished through the timely display of multiple choice questions. If the student answers the questions correctly, the study unit automatically continues. Post-training performance has shown an exceptionally high level of retention. The training technique also allows the student to

progress from the aircraft system study units through a systems trainer, the Cockpit Procedures Trainer (CPT), and finally to the Full-Mission Simulator. This procedure used by the commercial aircraft industry ensures that operations of all the training devices are cost-effective.

Normally, aircrews return to the flight training center every six months. One of the sessions includes an extensive briefing of commercial aircraft accidents or incidents, an operational review, and the yearly proficiency check required by FAA. The second session includes aircraft evacuation training, aircraft systems review, and line-oriented flight training (LOFT). LOFT creates line conditions during a simulator flight and allows the crew to face typical training problems. Any malfunctions, diversions, or other circumstances, such as a passenger experiencing a heart attack, may be introduced during the course of the four hour flight. The crew undergoing training must deal with the problems themselves which demonstrates the ability of the Captain to effectively use the human resources available. The LOFT instructor may not add any information or advice and may not interrupt the exercise to critique any actions until the simulation has been completed [Ref. 44].

C. FAA RULINGS CONCERNING VISUAL FLIGHT SIMULATION

The FAA has proposed new rules dealing with progress toward 100 percent simulator programs. The program is divided

into basically three phases. Phase 1 requires that the simulators be upgraded to the best that presently exists, with the capability of successful training in takeoff and landing maneuvers and ground handling of the aircraft. A Phase 2 simulator would allow the airlines the ability to upgrade to Captain a pilot currently qualified as a First Officer on the same type of aircraft. It would also allow lateral transition of a Captain or First Officer to a different aircraft. Following completion of transition training, Captains fly 25 hours and First Officers fly 15 hours under the supervision of a check pilot on regular revenue generating flights. Phase 3 is defined as total simulation training with corresponding requirements for improved aircraft data and better visual systems available to all crew members, including side window visuals. In 1979, Pan American was granted an exemption to perform a study to determine the feasibility of total simulator training. A group of 118 pilots was divided into a control group and experimental group with the experimental group completing the transition training without any aircraft time. At the end of the training, both groups were examined thoroughly by the FAA and Pan American check pilots with no discernible difference found in their performance. Excellent training results such as reported by Pan American point to implementation of Phase 3 training as a realistic objective by 1982-83 [Ref. 45].

In a recent interview with Mr. William Traub, Director of Flight Operations, United Airlines, the cost savings associated with upgrading the simulators to Phase 2 was outlined as follows:

B-727 AIRPLANE TRAINING AND CHECKING

1979 (Year of normal expansion and training)

1.	Total Aircraft Time -	694 hours
2.	Total Cost to Fly Above Hours -	$1,058,350
3.	Fuel Burned -	5,968,400 lbs.

1980 (Year of limited training)

1.	Total Aircraft Time -	434 hours
2.	Total Cost to Fly Above Hours -	$661,850
3.	Fuel Burned -	3,732,400 lbs.

This requirement to use the actual aircraft would have been alleviated with Phase 2 simulators. Appendix A of this thesis describes the simulator and visual system requirements for the three phases, as presented in Appendix H to Part 121 of the Federal Aviation Regulations.

D. A DESCRIPTION OF FLIGHT SIMULATION SYSTEMS

The approach toward Phase 3 simulation has been made possible by advances in several different fields including computer programming, hydrostatic motion systems, daylight computer generated image visual displays, available aircraft data, instructor integration, and maintenance [Ref. 46].

Accurate aircraft data have allowed the simulator to duplicate the aircraft more accurately, particularly in

ground effect and ground handling. Aerodynamic characteristics of an aircraft change when within approximately 300 feet of the ground and has been difficult to simulate until the present state-of-the-art. Better visual and motion systems are now simulating ground handling more accurately, and several airlines have opted for four or even six window displays to provide pilots with an all-around cockpit view. Ground handling may also include the effect of ice and snow [Ref. 47].

Improvements such as hydrostatic technology have been used to reduce friction in motion and control feel systems. Prior to this new technology, the pilot would notice a disconcerting "bump" especially during the return to the neutral position by the jack after the system had inputted a particularly large acceleration. Hydrostatic jacks reduce friction to about one-tenth of its previous value by eliminating direct contact between piston and cylinder wall. High pressure hydraulic fluid is leaked between the piston and wall and the pressure centralizes the piston because it acts equally in all directions [Ref. 48].

Control feel errors have been reduced to about one-half their previous value as a result of the simulator companies adopting electronic feedback controls. These components allow technicians to individually alter a particular parameter without introducing undesirable effects in other areas. This has

increased significantly the time the simulator has been made available to the user airline [Ref. 49].

Major airlines are emphasizing instructor integration into the cockpit while the student is undergoing training. This allows the instructor to devote more time to observing and instructing. Pre-programmed aircraft system faults, hand-held controllers, and full color CRT displays are training aids made available in the cockpit. An instructor could, for example, select a pre-programmed engine failure to occur at a particular altitude after takeoff. He could observe the method by which the crew complied with the emergency procedures, and without taking his eyes off them, input other faults through the hand-held controller. Both the crew and instructor could debrief the procedure by using the CRT and a printed copy of the plot of the aircraft position could be made, if desired [Ref. 50].

Most airline simulators are presently using visual systems with night/dusk CGI capability, using 6,000 to 10,000 light points to create the image; however, better computers are being developed which will allow daylight full color imagery to be developed. The FAA's total simulation plan (Phase 3) requires daylight CGI which typically costs twice as much as the night/dusk system.

Other improvements to simulator visual displays include using multi-window displays increasing the crew's field-of-view, and also decreasing the gap between the windows from five degrees to about one degree [Ref. 51].

Airline companies' utilization of sophisticated flight simulators must be carefully scrutinized since the lead time is about two years and a typical cost is about $5 million to $6 million. Typical cost of a two-window, night/dusk CGI is more than $500,000 while a four-window system would exceed $1 million (1980 dollars) [Ref. 52]. With costs of this magnitude, it is absolutely imperative that the simulators be an effective asset to flight crew training. The next part of this Section examines the training effectiveness of flight simulators realized by the major airline companies.

E. TRAINING EFFECTIVENESS

The state-of-the-art technology in flight simulation systems combined with the professional training concept outlined in Part B of this Section provides the basic foundation for training an airline pilot; however, the <u>real</u> test is to evaluate whether the skills learned will transfer to the aircraft.

Many studies have been conducted by major airline companies to determine whether or not flight simulators can provide the necessary training to economically justify the costs of a visual simulator system, and more importantly, to determine whether critical maneuvers that would be unsafe in the aircraft could be satisfactorily learned in the simulator. This part of Section III will review three such studies.

The first study to be reviewed concerns the requirement for aircrews to conduct three takeoffs and landings in the

actual aircraft as a fundamental requirement to maintain or reinstate the pilot's currency in that particular type aircraft. American Airlines questioned the effectiveness of this requirement since experience had shown that requalification flights were normally made on days with excellent weather conditions and at unrealistic airplane weights. If the requalification flights were performed in visual simulators, the pilot could demonstrate proficiency in both day and night conditions and at aircraft weights normal to line operations. To increase the completeness of training, varying conditions such as reduced visibility and crosswinds could be introduced by using the simulator.

American Airlines used the two-group concept in conducting the study. The control group complied with Federal Aviation Administration regulations in conducting their takeoff and landing requirements while the study group used an approved digital flight simulator with a color visual system. After the appropriate training both groups had their first two landings evaluated by an approved check pilot. There were 80 pilots in each group with the pilots coming from all types of aircraft including the Boeing 727, 707, 747, and McDonnell-Douglas DC-10. The training provided each pilot was dependent on the time period since the last currency rating.

During the training period the FAA observed 13 line takeoffs and landings for the control group and 81 line takeoffs and landings for the study group. The average grades for the

line takeoff and landings for the control group were 3.33 and 3.40 while the study group had average grades of 3.49 and 3.60 respectively. These scores were based on a five point rating scale. It should also be noted that weather conditions for both groups during the evaluations included day, night, dusk, dawn, and a variety of visibility and crosswind conditions [Ref. 53].

Questionnaires concerning the simulator training were completed by 41 of the 80 subjects within the study group. Forty-four percent of the pilots favored the simulator program without any reservations and an additional 37 percent accepted the simulator program as adequate in view of the economic situation or with some added qualifications, one of which was that a minimum level of pilot experience be required before using the simulator in lieu of the airplane. The most common recommendation was a minimum of 100 hours pilot experience in that type aircraft [Ref. 54].

Based on analysis obtained from this study, American Airlines recommended to the FAA that pilots who had not completed three takeoffs and landings within 90 days be allowed to requalify using a visual simulator training program. This recommendation was accepted and has been incorporated within the regulations as long as the simulator system has been approved by the FAA. Requalification in the aircraft is a very costly program, therefore, this ruling has proven to be an economical improvement for the commercial airline industry.

Practicing maneuvers in the simulator that would be unsafe in the aircraft is a second positive area supporting training effectiveness. During the 24 month period between July 1965 and July 1967, 38 percent of jet accidents resulting in fatalities or airframe destruction occurred during training. Of these accidents, 37.5 percent occurred when the pilot was practicing a simulated engine failure on takeoff [Ref. 55].

Between September 1, 1971 and January 12, 1972, American Airlines conducted training in the simulated engine failure maneuver through extensive use of visual flight simulation. The following groups of pilots were studied:

DC-10	Captains -	37
DC-10	Co-pilots -	24
B-747	Captains -	8
B-747	Co-pilots -	5
B-707	Captains -	38
B-707	Co-pilots -	7
B-727	Captains -	38
B-727	Co-pilots -	18

After simulator training, the pilots were checked in the aircraft by qualified examiners with the following results:

		PASS	FAIL	% PASS	AVG. NO. OF PRACTICE PERIODS IN THE SIMULATOR
DC-10	Captains	36	1	98	5.2
DC-10	Co-pilots	24	0	100	5.5
B-747	Captains	8	0	100	6.4
B-747	Co-pilots	5	0	100	5.2
B-707	Captains	36	2	95	6.3
B-707	Co-pilots	7	0	100	5.8
B-727	Captains	38	0	100	5.0
B-727	Co-pilots	18	0	100	4.4

In addition to the Pass/Fail score given, all examiners graded pilots in four areas including: lateral control,

heading control, climb speed, and procedures. There was a general consistent relationship between grades given in the simulator and on the first performance in the aircraft. Data actually showed that pilot performance in the aircraft was slightly higher than in the simulator.

As a result of the success of this study, it was recommended that all training and checking for maneuvers involving power plant and critical systems failures be conducted in simulators equipped with visual systems [Ref. 56].

Beginning in June 1967, four major airline carriers participated in a study determining the appropriate methods for training pilots in landing three and four engine aircraft with 50 percent power available. Realizing that all carriers did not have the same types of training equipment, three programs were used to gather data for the report. There were three prerequisites required for each program including: (1) a high level of proficiency in normal approach and landing before using 50 percent power; (2) performance characteristics of 50 percent power aircraft must be completely understood by the pilot in training; and (3) a high proficiency standard of operating and landing an aircraft with 50 percent power loss must be attained [Ref. 57].

The programs included: (1) a simulator (without visual) and aircraft combination with subcomponents of the maneuver such as configuration changes being mastered in the simulator and with actual maneuvers in the aircraft being accomplished

at altitude; (2) complete training in a visual simulator with satisfactory performance on normal and one engine inoperative landing being required before a 50 percent power loss landing was attempted; and (3) complete training in the aircraft with individual components being taught and integrated at altitude prior to actually performing the landing.

A very important result of this study showed that a high degree of success was achieved with each of the programs, emphasizing the fact that flight simulators had proven to be an ideal device for combining knowledge and skill requirements necessary to execute the 50 percent power loss on landing maneuver. With the effectiveness results of the three programs being the same, the airline companies using the "simulator only" training method showed a significant cost savings as a result of fewer actual aircraft hours being utilized.

F. COST-SAVINGS OF FLIGHT SIMULATORS

This part of Section III will quantitatively show the cost savings realized as a result of data obtained from both American and Delta Airlines. In the case of American Airlines data, the author concentrated on the costs associated with transitioning a Captain from one aircraft type to another type.

Table III-1 provides data for three aircraft flown by American Airlines. In order to conduct a direct operating cost comparison, this author made the assumption that, if a simulator was not available, each simulator training hour would

TABLE III-1

AVERAGE TRAINING HOURS AND COSTS PER HOUR
IN SIMULATOR AND AIRCRAFT FOR CAPTAIN TRANSITIONS
(Source: American Airlines)

Aircraft	1980 Hours		Direct Operating Cost*/Hr, 1980		No. of Captains Transition in 1980
	Aircraft	Simulator	Aircraft	Simulator	
B-747	1.4	17.3	$6467	$121	37
B-727	1.5	18.2	2150	107	60
DC-10	1.7	23.0	4199	118	67

*Direct Operating Cost is defined as fuel, maintenance, and insurance for the aircraft and maintenance plus insurance for the simulator.

TABLE III-2

DIRECT OPERATING COST COMPARISON
(Source: American Airlines)

Aircraft	Simulator and Aircraft	Aircraft Only
B-747	$ 412,443	$ 4,474,517
B-727	310,344	2,541,300
DC-10	660,104	6,948,925
Total	$1,382,891	$13,964,742

have been performed in the aircraft. Table III-2 shows this direct operating cost comparison.

For American Airlines, the direct operating costs associated with using the simulator and aircraft in the training program was only 9.9 percent of the costs that would have been incurred if only the aircraft were used. It must also be remembered that this was only for Captains transitioning to another type of aircraft.

The Assistant Manager of Flight Training, Delta Airlines, provided this author with training and cost data for all line aircraft flown by the company. Table III-3 outlines the direct cost per hour of aircraft training versus simulator training for Delta's current fleet of aircraft. The cost of fuel, oil, and taxes is based on a fuel price of $1.05 per gallon, plus $.0245 per gallon for oil and taxes. Maintenance burden costs are computed at 60 percent of the fully allocated rate.

Table III-4 provides cost savings associated with using the simulator systems for the different aircraft. The hours shown for each simulator system are the total hours used to train all crewmembers in that particular aircraft. Delta confirmed the assumption made by this author that if the simulator were not available, those training hours would be flown in the aircraft. Consequently, the cost per hour to compute the savings that result is the net aircraft cost calculated in Table III-3.

TABLE III-3

COST COMPARISON OF AIRCRAFT TRAINING
VERSUS SIMULATOR TRAINING
(Source: Delta Airlines)

Cost Per Hour for Aircraft	DC-9	DC-8	B-727	L-1011
Fuel, Oil, and Taxes	$ 987	$2050	$1603	$2547
Direct Maintenance	130	205	110	385
Maintenance Burden	81	143	64	193
Total Aircraft Cost	$1198	$2398	$1777	$3125
Simulator Cost Per Hour				
Maintenance	$ 85	$ 85	$ 85	$ 85
Net Aircraft Cost	$1113	$2313	$1692	$3040

TABLE III-4

COST SAVINGS
(Source: Delta Airlines)

Aircraft	Annual Simulator Hours	Net Aircraft Cost	Savings
DC-9	3,012	$1113	$ 3,352,356
DC-8	1,315	2313	3,041,595
B-727	12,571	1692	21,270,132
L-1011	3,300	3040	10,032,000
		Total Savings -	$37,696,083

The cost (1980) of procuring the simulator systems that are being utilized by Delta Airlines is approximately $41,500,000. Since the savings were $37,696,083, this would allow the initial cost to be recouped in approximately 1.10 years.

G. SUMMARY

This Section has described the use of visual flight simulators by major commercial airline companies. The companies have consolidated their initial, transition, and recurrent training, taking advantage of standardization and economies of scale. The FAA has worked in close harmony with the airlines so that the simulator systems, with their potential for training, could be used in the most effective and efficient manner. Training effectiveness was successfully measured using simulator systems in such areas as takeoff and landing requalification and practicing the hazardous maneuvers of losing an engine once the aircraft reached takeoff commital speed and 50 percent power loss during final approach. The final part of Section III quantitatively describes cost savings that have been realized by two major air carriers.

There are basically two areas which highlight major differences between commercial airlines and military utilization of visual flight simulators. First, commercial airlines do not get involved in the initial training of a pilot. For the most part, airline companies hire pilots with many hours of

military or private flying. Secondly, the missions are entirely different. Simulating air-to-ground delivery of ordnance or air-to-air combat is an entirely different environment than teaching someone to fly an approach and landing to a major aerodrome such as San Francisco or Denver. Can visual flight simulation be effective when used in military training? Section IV outlines training effectiveness of visual flight simulators within the military.

IV. TRAINING EFFECTIVENESS OF MILITARY FLIGHT SIMULATORS

A. GENERAL

History indicates that the single most decisive factor in winning and losing wars is the adequacy of training and the motivation of the personnel who make up the combat forces. During peacetime, the realism of training is difficult to maintain without jeopardizing the safety of these personnel and their valuable equipment. Because of this problem, the Department of Defense has invested millions of dollars to procure simulators which assume to provide realistic and effective training at reduced costs. As a result, many studies have been conducted to gather and analyze data in order to determine quantitatively and qualitatively that simulators are devices that enhance training effectiveness.

Simulator effectiveness is typically assessed through the use of a transfer of training paradigm [Ref. 58]. Experimental and control groups are normally evaluated both objectively and subjectively in order to ascertain whether a transfer of training occurred between the simulator device and the system. The results of this transfer may either be positive or negative. Positive transfer implies that less time is needed in the aircraft in order to attain a predetermined performance criterion as a result of training in the simulator, while

negative transfer indicates that more aircraft time is required than would have been necessary if the simulator were not used in the training process. The methodology of data gathering would require that experimental groups be exposed to a pre-designed simulator syllabus and then performance would be measured in the aircraft, while the control group would receive their training only in the aircraft before completing the performance measurement.

It is the purpose of this Section to: (1) describe some methods that have been developed to measure the effectiveness of the flight simulator; (2) discuss critical factors influencing simulator training effectiveness; and (3) present an analysis of training effectiveness data from actual military applications.

B. METHODS OF MEASURING TRAINING EFFECTIVENESS

Computational formulas for measuring training effectiveness have been developed using the relationship between simulator substitution hours and in-flight hours. Table IV-1 describes how the methods are computed.

Interpretation of the calculations indicates that the larger the positive value of syllabus reduction, the more <u>effective</u> the simulator system, and the smaller the Flight Substitution Ratio (FSR), the more effective the substitution. FSR defines the rate at which flight time is being replaced by the simulator and thus reflects <u>efficiency</u> of the device.

TABLE IV-1

METHODS FOR MEASURING TRANSFER EFFECTIVENESS
(Source: Training Analysis and Evaluation Group, Report No. 43)

Computation	Formula
Percent Flight Syllabus Reduction	$\frac{\text{Original Flight Hours} - \text{New Flight Hours}}{\text{Original Flight Hours}} \times 100$
Flight Substitution Ratio (FSR)	$\frac{\text{New Simulator Hours} - \text{Original Simulator Hours}}{\text{Original Flight Hours} - \text{New Flight Hours}}$
Transfer Effectiveness Ratio (TER)	$\frac{\text{Original Flight Hours} - \text{New Flight Hours}}{\text{New Simulator Hours} - \text{Original Simulator Hours}}$

Transfer Effectiveness Ratio (TER) describes the ratio of flight hours saved to the time spent in the simulator [Ref. 59]. All the flight and simulator hours data used in the three equations are the times required for the subject pilots to accomplish a predetermined effectiveness criterion.

Studies conducted between 1967 and 1977 support the fact that simulators show positive transfer effects to the aircraft; however, there were wide variations in the effectiveness of different simulators and of the same simulator when used for different types of training [Ref. 60]. The TER is a measure used to identify the type of task for which the simulator would be more cost effective than the aircraft. Using the learning curve theory, the amount of improvement per hour of training is expected to decrease as training progresses. This implies that the effectiveness of a simulator is the greatest at the beginning of training and diminishes during the training period. Despite this diminishing effectiveness, it is cost effective to use the simulator up to the point where the TER equals or becomes less than the ratio of simulator to aircraft operating cost [Ref. 61].

Although the effectiveness of flight simulators has been quantitatively measured using the formulas previously explained, factors that influence the effectiveness have received little attention. Part C of this Section will address these factors.

C. FACTORS INFLUENCING SIMULATOR TRAINING EFFECTIVENESS

Even though state-of-the-art technology has allowed simulator systems to be developed with remarkable realism, there remains much to be learned about training with these devices. There is no quantifiable data to support some of the factors believed to influence simulator training effectiveness; however, where inferences can be made and supported by a consensus, these factors must be carefully considered by those responsible for simulator design. The following paragraphs discuss selected factors which influence training effectiveness.

1. Design of Simulator Systems

Important in the design of simulator systems is the fidelity of the system itself and training aids incorporated such as instructor station displays, playback, performance recording, freeze, and performance measurement. The level of fidelity is often equated to physical correspondence between the simulator and the real world. Two critical areas contributing to the level of fidelity are visual systems and motion bases.

When simulating aircraft environments, some areas of training, such as air-to-ground weapons delivery and air-to-air combat, require visual systems for effective training. On the other hand, instrument flying would not require such a system. This theory, along with other factors that will be discussed in this Section, have motivated the military to

evaluate procuring simulator systems which include part-task trainers designed to train within particular areas of military flying or at different levels of pilot performance. As an example, when a student begins flight training, a full fidelity simulator system could actually serve to confuse him or her by having attributes such as visual and motion systems which would divert the student's attention from the actual transfer responses desired. Conversely, advanced training requires the high fidelity systems which most closely simulate the actual aircraft through sight, sound, and motion. Using a low fidelity system at this point in the training cycle would seriously reduce the effectiveness because of the inability to provide distractions that would be experienced during aircraft operation [Ref. 62]. In addition, motion bases provide a significant contribution to the costs associated with procuring a simulator system; therefore, extensive study and evaluation should be completed to ensure that motion systems are incorporated within the part-task trainers that will result in the most effective training.

During the period of August 1976 through March 1977, the Air Force Human Resources Laboratory (AFHRL) conducted a study to determine how simulator training with a full six degree motion system affected air-to-ground weapons delivery training. Twenty-four recent graduates of the pilot training program were divided into three groups of eight subjects each. The groups were ranked equally in the areas of flight

grades and flight experience. The control group received no simulator training. Experimental Group I received training with a motion simulator and Experimental Group II's training was in a simulator with no motion. The control group received two familiarization flights in the F-5B aircraft prior to the flights for score. There were two ordnance carrying flights with nine bombing patterns made on each flight. The pilot had six bombs on the aircraft so he would make one practice pattern and then drop two bombs. This scenario was repeated for the 10°, 15°, and 30° delivery patterns. The experimental groups received eight one-hour sessions in the simulator practicing the three tasks. Following these sessions, the experimental groups completed the two familiarization flights and then flew the same score-taking flights. The method for measuring the bombing score was the circular error probable (CEP), which is the radius of a circle in which 50 percent of the projectiles would be expected to fall. Table IV-2 lists the observed means for each group on the three bomb delivery tasks in the aircraft.

Additionally, scoreable bombs were defined as those with a CEP of less than 300 feet. The results of the three bombing tasks showed that 72 percent of the control group's bombs were scoreable while 86 percent and 85 percent of Experimental Groups I and II were scoreable.

Statistically, there were no significant differences found between the two experimental groups in the number of

TABLE IV-2

BOMB DELIVERY CIRCULAR ERROR MEANS
(Source: AFHRL Study TR-77-29)

	10° Dive Angle	15° Dive Angle	30° Dive Angle
Control Group	200 ft.	180 ft.	204 ft.
Experimental Group I (Motion)	148 ft.	138 ft.	169 ft.
Experimental Group II (No-Motion)	138 ft.	144 ft.	159 ft.

qualifying bombs, the number of scoreable bombs, or the bomb delivery circular error. These results indicated that six-degree-of-freedom platform motion did not enhance the training value of the system. To reemphasize the fact that the level of fidelity needed within the system should be carefully evaluated, it should be noted that the aircraft simulated was a T-37 (with sighting device) and still there was a significant transfer of training to the F-5B. This study confirmed the theory developed by Prophet and Boyd in 1970 that a low fidelity device could provide considerable transfer of training when properly utilized [Ref. 63].

2. Training Programs

Even though sophisticated simulator systems have been procured by the military, reports have been documented in which the importance of training program design has been ignored allowing simulators to be misused or used inefficiently [Ref. 64]. Training programs should be implemented that interface with the simulator devices. A dynamic flight simulator used as a Cockpit Procedures Trainer (CPT), for example, is not being used effectively. A procedure that has proven to be most effective is to develop and utilize training programs that are presented in the context of a simulated mission activity as opposed to an abstract training exercise. Literature has also shown that skills taught within such a training program were retained to a greater degree than the abstract training exercise [Ref. 65].

3. Personnel

Trainees and instructors both play a significant role in the training effectiveness of flight simulators, particularly in the areas of qualifications and prior experience.

As was highlighted by commercial airlines' use of individualized programs, all investigations of human learning are subject to the influences of task-related aptitudes of the trainees. When a fixed amount of time is allotted, trainees with a high aptitude are able to transfer more training to the aircraft; however, where training is to a fixed performance level and training time is allowed to vary, both high and low aptitude students attain this performance level. The ability of a simulator to train less experienced military pilots has been questioned; however, studies have shown that the flight training devices and programs, if optimally designed, are effective for pilots with differing experience levels [Ref. 66].

Training effectiveness of a simulator system is highly dependent upon the instructor's input into the program. Effectiveness can be degraded considerably if instructors are not fully aware of the capabilities and limitations of the system. In a study sponsored by the Aerospace Medical Laboratory, it was determined that instructor ability and fidelity of simulation were related in such a way that as

fidelity increased the necessary level of instructor ability could decrease, and, conversely, as fidelity decreased instructor ability should increase. Unfortunately, observations had shown that just the opposite occurred, resulting in a reduction of the simulator's training effectiveness [Ref. 67].

A final personnel point to support training effectiveness is the single instructor concept. Even though this variable has not been adequately studied, there appears to be an increase in effectiveness when a single instructor is responsible for both simulator and aircraft training, allowing instruction given in the simulator to be more compatible with that given in the aircraft. This reduces any potential negative transfer that could occur as a result of instructor-peculiar performance requirements [Ref. 68].

4. Expectations

What an instructor and trainee expect from a simulator system can affect the training effectiveness. If simulators are viewed as useful only as procedures trainers or as instrument trainers, they tend to be used only in that capacity, even though possibly offering a greater range of training opportunities. Attitudes of the personnel can lead to certain expectations. As an example, it was noted that older pilots tended to make less effective flight instructors, possibly because of a hesitancy to adopt new teaching methods such as the use of simulation. This hesitancy could have occurred as a result of unsatisfactory experiences with older

simulators, resulting in greater confidence in in-flight training. These expectations, especially of instructors, must be realized before training effectiveness of the system is possible [Ref. 69].

Effective simulator training is dependent upon a proper combination of the system, training programs, personnel, expectations, and other factors. These factors, which may not be that influential in isolation, may become very volatile, either positively or negatively, when acting in combination. Information about the simulator's design, the way it was used, and the attitudes and expectations of the personnel involved should be disseminated, resulting in greater benefits to simulator training programs under development. The first step in this process is to recognize a need for better communication among the users of simulator systems which would lead to increased training effectiveness through greater familiarity with the processes [Ref. 70].

Measuring the training effectiveness of the flight simulators in military scenarios has been performed through many independent research analyses. The next part of Section IV will describe the results in the mission areas of: (1) instrument flying in undergraduate pilot training, (2) air-to-surface weapons delivery for the A-10 aircraft, (3) air-to-air combat training, and (4) night carrier landing training in the A-7E.

D. TRAINING EFFECTIVENESS REALIZED USING MILITARY FLIGHT SIMULATORS

1. Instrument Flying In Undergraduate Pilot Training

The study used as a reference for this section was evaluating the simulator system mix that should be utilized in the instrument training program; however, information made available is pertinent to demonstrating training effectiveness of such devices in teaching undergraduate pilots the mission of instrument flying.

The study, coordinated by AFHRL, was conducted during the period of March 1976 through July 1977. During this period, subject pilots were divided into three groups. The first group received all instrument training in the aircraft. The second group received all ground instrument training in the Advanced Simulator for Pilot Training (ASPT) and all procedures training in the existing T-37 instrument procedures trainer (T-4, no visual and limited motion). The third group conducted most of the instrument training in the ASPT with the remainder of the instrument training and all of the procedures training in the T-4. It is not the author's intent to discuss the proper mix of these two trainers as recent phone conversations with the Instrument Flight Simulator personnel at Williams AFB, Arizona, have pointed out that the T-4 is presently not fully operational and is only being used as a Cockpit Orientation Trainer (COT). The important fact to highlight is that data were obtained to compare hours of

training between the simulator and the aircraft and also compare the average "checkride" scores that were realized by the subjects at the end of their training periods. Although the group mean scores for the T-37 "checkrides" varied somewhat between the experimental and control groups, none of the differences were statistically significant at the 90 percent confidence level. It should be noted that the control groups received an average of 11 instrument training sorties in the aircraft while the experimental group received an average of 1.9 sorties [Ref. 71]. Table IV-3 outlines the average simulator hours and aircraft hours used by the experimental and control groups as well as their respective average "checkride" scores.

TABLE IV-3

COMPARISON OF EXPERIMENTAL AND CONTROL GROUP FOR INSTRUMENT STAGE TRAINING (Source: AFHRL Study TR-77-61)

	Control Group	Experimental Group
Average Simulator Hours Used	17.3	28.0
Average Aircraft Hours Used	15.8	2.5
Average "Checkride" Scores	90.52	87.32

Based on the data obtained, it was determined that use of flight simulators could be very effective in instrument training. The present syllabus within Air Force undergraduate

pilot training requires 22.1 hours in the simulator and 5.2 hours in the aircraft for Instrument Phase in the T-37 and 31.2 hours in the simulator with 5.6 hours in the aircraft for Instrument Phase in the T-38. Even with this syllabus description, the average percent of pilots that qualify on their first instrument "checkrides" has been 85 to 90 percent supporting simulator training effectiveness within this mission [Ref. 72].

2. Air-to-Surface Weapons Delivery for the A-10 Aircraft

During the period that Gray and Fuller were conducting their transfer of training studies from the T-37 simulator to the F-5B aircraft, the A-10 aircraft was being introduced into the Air Force inventory. This is a single-place airplane with a primary mission of air-to-surface weapons delivery; therefore, simulator training was especially critical due to the fact that the first flight must be a successful solo and the flights are composed of hazardous activities.

Since there were no A-10 simulators in the inventory, the Tactical Air Command (TAC) and AFHRL modified the ASPT to the A-10 configuration. This allowed two objectives to be achieved. First, it provided AFHRL the opportunity to further their research in air-to-surface weapons delivery training with a simulator, and second, it provided the A-10 neophyte pilot with a training device for conversion and surface attack tasks [Ref. 73].

It was recognized from the beginning that the sample size would be small because of the recent introduction of the aircraft; however, this drawback was outweighed by the validity of the sample. The subjects were very representative of the population because both the students and instructors were members of an operational combat crew training squadron. It was determined that assessment of the results of the study would be based on measures highly relevant to actual operations [Ref. 74].

The modification of the ASPT to the A-10 configuration was very precise in the area of aircraft performance and handling qualities. Although the cockpit did not have complete A-10 instrumentation, all the instruments operated, and the CGI system depicted Davis-Monthan AFB and Gila Bend Gunnery Range with reasonable fidelity [Ref. 75].

The study consisted of six air-to-surface weapons delivery tasks including dropping bombs at different dive angles and firing the internally-mounted gun. Bomb scores were determined using the CEP as the criterion measure while the percentage of hits per rounds fired was used to score the firing of the gun.

There were 24 students participating in the study. The experimental group (17 students) received an average of six hours of training in the simulator prior to flying the aircraft. The control group (7 students) did not receive any

practice in the simulator before flying the aircraft. There were 12 sorties flown in the surface attack weapons delivery phase. The first seven sorties were conventional deliveries with 30° dive bomb (DB), 20° low angle low drag (LALD), and 15° low angle bomb (LAB). The remaining five sorties included 5° low angle strafe (LAS) and "Pop-up" deliveries using 20° LALD and 15° LAB [Ref. 76]. "Pop-up" deliveries, as opposed to conventional deliveries, means ingressing into the target area at a low altitude, pulling the nose of the aircraft up to a predetermined pitch attitude, climbing to visually acquire the target, and then completing the ordnance delivery. Figures IV-1 through IV-5 graphically portray the average CEP scores, in meters, that were realized on each sortie for bombing tasks, and Figure IV-6 plots the percentage of rounds through the target for the low angle strafe task.

The data made available to this author were only the average circular error probables for each sortie. To support the fact that all tests were run at the 5 percent level of significance, this author applied a t-test of statistical significance to the average data to compute the Prob-value (PV) for each task. The null hypothesis ($H_o : \mu_1 - \mu_2 = 0$) implied no difference between the control group and the experimental group while the alternative hypothesis ($H_1 : \mu_1 - \mu_2 > 0$) implied that the average CEP for the control group was greater than the experimental group. Table IV-4 outlines the t-statistic value and the Prob-value for

FIGURE IV-1
30° DIVE BOMB

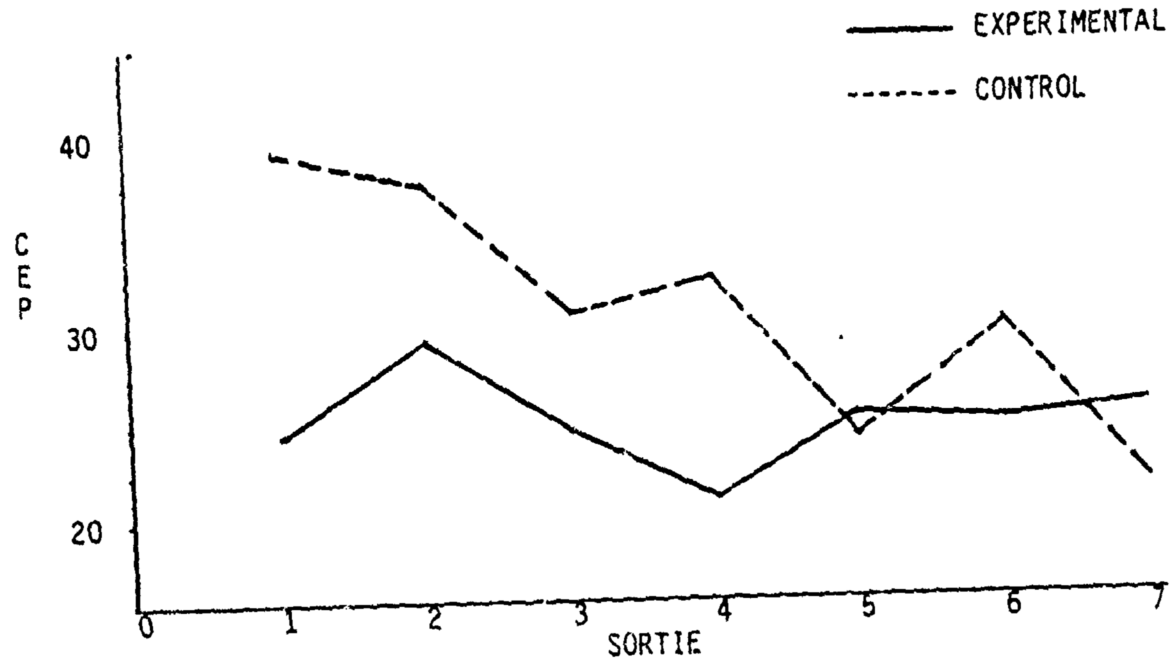


FIGURE IV-2
20° LALD DIVE BOMB

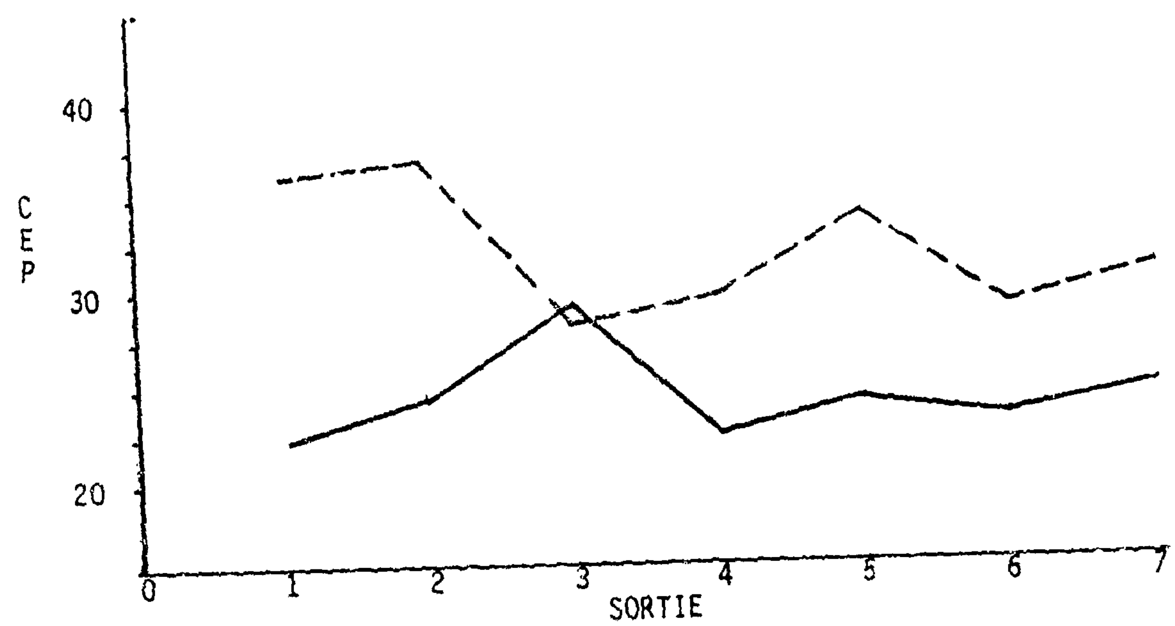


FIGURE IV-3
15° LAB DIVE BOMB

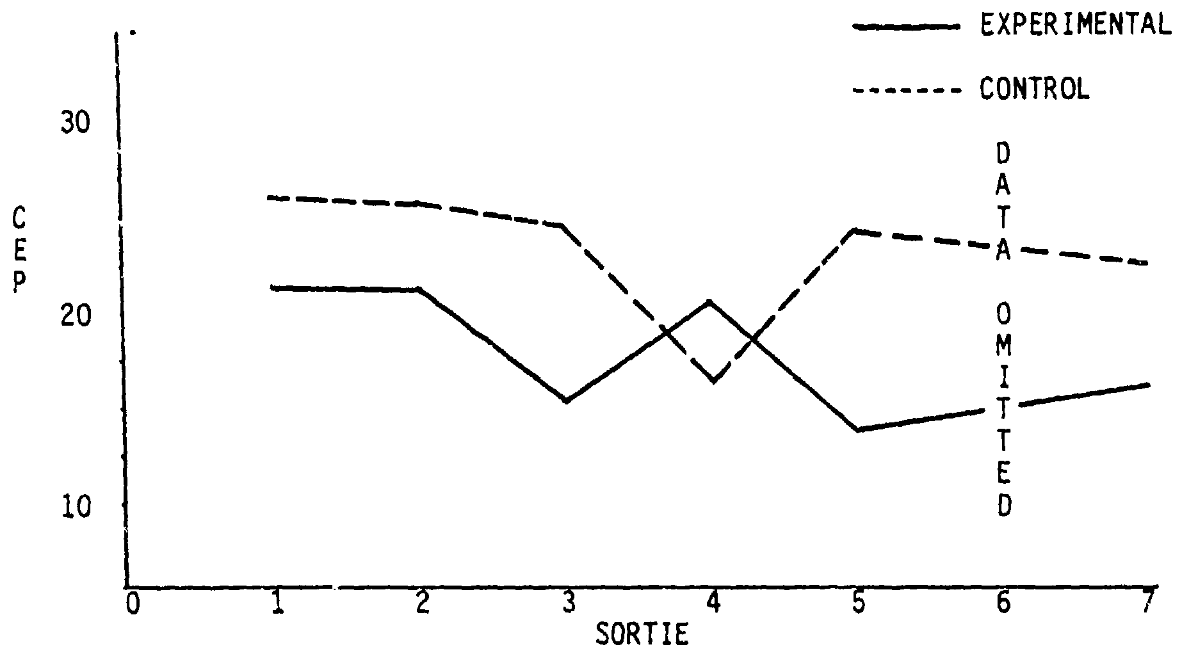


FIGURE IV-4
20° LALD "POP-UP"

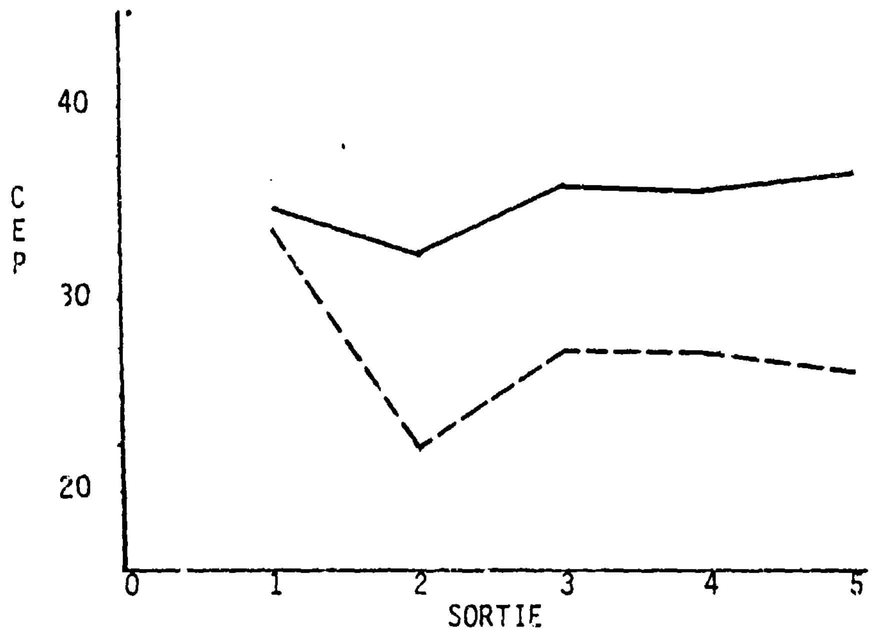


FIGURE IV-5
15° LAB "POP-UP"

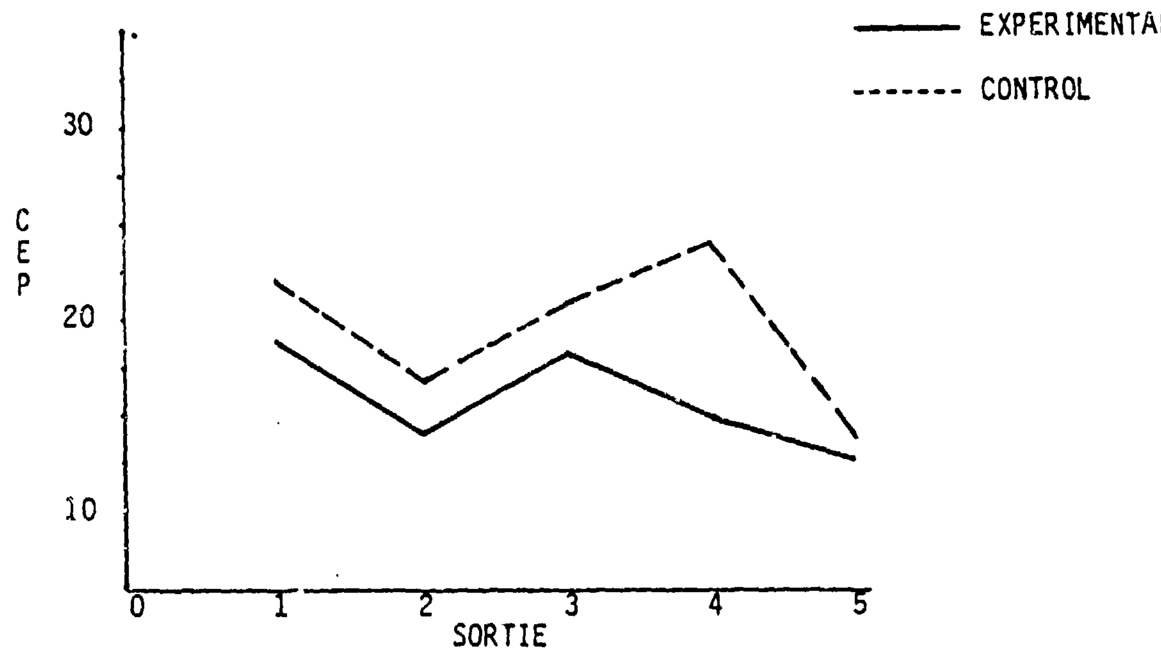
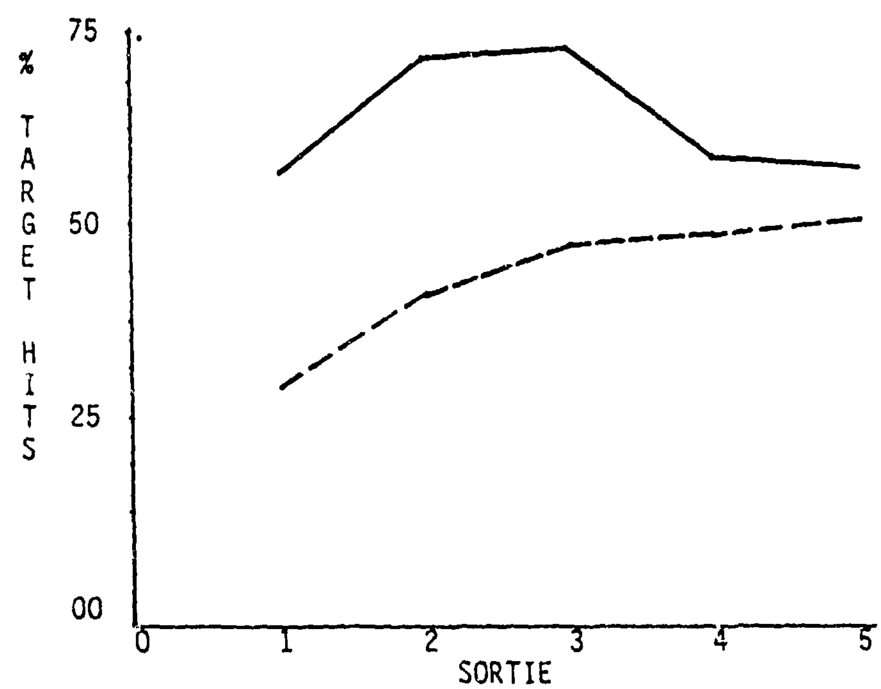


FIGURE IV-6
5° LOW ANGLE STRAFE



each task. It must be remembered that the values were calculated from average scores and are not as valid as raw data. Since the PV for each task, except the 20° LALD "Pop-up," is less than .05, the null hypothesis (H_O) should be rejected at the 95 percent confidence level, meaning that there is a statistically significant difference between the control group and the experimental group.

TABLE IV-4

t-STATISTIC AND PROB-VALUES
FOR A-10 AIR-TO-SURFACE TASKS

Task	t-Statistic (ts)	Prob-Value (PV)
30° Dive Bomb	2.198	.024
20° LALD Dive Bomb	4.774	.0002
15° LAB Dive Bomb	2.63	.013
20° LALD "Pop-up"	-3.78	.997
15° LAB "Pop-up"	1.910	.046
5° LAS	3.929	.002

As depicted on Figure IV-4 and supported by the average-based t-statistic and PV in Table IV-4, the control group exhibited significantly better performance than the experimental group in the 20° LALD "Pop-up" task. It was determined that ASPT's flat visual flight plane offered limited depth perception cues. As a result, the ability to judge angle-off approaches and apex positioning made the

"Pop-up" weapons delivery task more difficult to satisfactorily simulate [Ref. 77].

In conclusion, it was determined that three ASPT sorties (6 hours) provided highly effective training. The data indicated that the simulator also provided more beneficial training in the conventional delivery and low angle strafe than in the "Pop-up" delivery. Additional benefits included flight safety and ease of instruction on the controlled range. Mechanical and procedural problems could be either eliminated or reduced in the simulator, leaving more time for instructing weapon delivery techniques on the actual range [Ref. 78].

3. Air-to-Air Combat Training

State-of-the-art simulators provide an excellent opportunity to enhance training effectiveness in air-to-air combat. If the aerodynamic capabilities are properly programmed, it allows the pilot an opportunity to explore the edges of the maneuvering envelope without sacrificing safety of flight. It also gives the pilot excellent training in utilizing different weapons systems such as missiles and guns and also to develop both offensive and defensive tactics.

The U.S. Air Force, through a joint program with the Vought Corporation, has developed a Good Stick Index (GSI) for measuring the training effectiveness of air-to-air combat simulation. The GSI was formulated from data gathered in Vought's Air Command Engagement Simulator (ACES). The ACES

consists of two cockpits, each situated within 16 foot diameter spherical screens. It utilizes F-4 cockpits with complete instrumentation plus the ability to program into the computer MIG-21 aerodynamic characteristics in order to provide training in dissimilar aircraft engagements [Ref. 79].

Normally, classes utilizing the ACES Training Program consisted of eight students. The students would fly approximately 8.5 to 9.0 hours in the simulator between Monday and Friday. The study discussed in this part of Section IV examined data from four of twelve classes which used the simulator from 3 April 1978 through 23 June 1978. During this period, 89 students were evaluated. At the end of the training period, a "turkey shoot" tournament was conducted in which the students flew one-versus-one engagements with double elimination rules. It was the intent of the study to statistically validate the GSI as a predictor of the "turkey shoot" winner, investigate improvement in the GSI by varying the weight factors of the parameters, and introduce additional parameters to determine whether the predictions could be improved. These objective evaluations were also compared with predictions of the instructor pilots to assess its agreement with expert opinion [Ref. 80]. (Readers interested in further details concerning the study or the statistical analysis are encouraged to read AFHRL-TR-79-15 which may be obtained from the Air Force Human Resources Laboratory, Air Force Systems Command, Brooks AFB, Texas.) This author intends to define

the GSI and show, through the data gathered from the four classes, that the pilot's ability did improve during the one week of training.

Computation of the GSI score was accomplished using data obtained from the predictor variables measured by the computer system. The data were recorded when the simulator was flown against five canned targets. The five canned targets consisted of two cinetrack runs and three head-on passes. The coefficients of the equation were computationally weighted to provide an ideal score of 1000. The equation developed is,

$$GSI = 4.6(70 - MILERR) + 0.86\ (PANG) + (O/D - 35)$$
$$+ 0.5\ (180 - TTFK)$$

where:

MILERR = average mill error over two cinetrack runs while range is less than 3000 feet.

PANG = average percentage of engagement time in pointing angle advantage over two cinetrack runs at a range less than 3000 feet.

O/D = average ratio of offensive to defensive time against the head-on targets. Offensive time is the time the target aircraft is in the front hemisphere of the piloted aircraft.

TTFK = average time to first kill (seconds) from beginning of run until student achieves first kill against head-on targets with gun or heat missile. [Ref. 81]

Table IV-5 lists the Monday and Friday GSI scores for 27 pilots tested during this study. Hypothesis testing is used to compute the t-statistic and the PV from the actual data. The null hypothesis is that there is no difference in

TABLE IV-5

PILOT GSI SCORES BEFORE AND AFTER SIMULATOR TRAINING
(Source: AFHRL Study TR-79-15)

Pilot No.	After Training (Friday)	Before Training (Monday)
1	595	359
2	601	312
3	589	266
4	547	125
5	499	309
6	549	393
7	552	304
8	794	210
9	447	531
10	562	234
11	570	304
12	494	199
13	487	393
14	851	687
15	739	391
16	751	553
17	531	247
18	527	368
19	716	577
20	581	364
21	681	550
22	571	264
23	566	553
24	515	187
25	616	145
26	690	414
27	773	529

HYPOTHESIS TESTING

H_o: $\mu_A - \mu_B = 0$

H_1: $\mu_A - \mu_B > 0$

$t_s = 7.039$ df = 52

PV = .000

the GSI between Monday and Friday versus the alternative hypothesis that there exists a statistically significant difference. Since the PV is less than .05, we may reject the null hypothesis that the population means are equal and accept the alternative hypothesis that the Friday GSI score is greater than the Monday score.

Through the ACES, the Tactical Air Command has been able to complement and reinforce flight training in the air-to-air environment. The program has been developed to optimize simulation training, so that it will enhance the flight syllabus, not replace it. The simulator system involves all facets of one-versus-one similar and dissimilar training, including the ability to train with all ordnance systems. The debriefing ability includes data recording, replay, and video recording. The scoring system looks at ordnance firing conditions and combat management. Every tenth bullet is scored and the attacker's "g" and angle of attack are recorded along with the aiming error, range, angle off, and target crossing angle. Missile firing data is evaluated to determine if the missile was fired within the proper envelope, and, if not, which parameters were not satisfied.

The cost of operating the simulator is approximately \$250 per hour per cockpit compared to the operating cost of the F-4 which is about \$1500 per hour. These values take on much greater meaning when one considers that during a one hour flight a pilot would experience approximately three

engagements in the aircraft and 15 engagements in the simulator. During the one week's training a pilot will receive an average of 134 engagements [Ref. 82].

General Robert Dixon, Commander of the Tactical Air Command, reemphasized the value of air-to-air simulation training when he stated,

> With today's advanced state-of-the-art in lethal air combat weapons systems, TAC feels that training must be better than ever before so that every advantage of the system over those of the enemy may be fully exploited by the key ingredient of the system, the man. TAC must, through optimized training, make the combat pilot's capability match that of his equipment. His appraisals, decisions, and actions must match the speed and accuracy of his machine. And, in these austere times, the Air Force is particularly interested in improved pilot capability without an appreciable increase in cost. [Ref. 83].

This improved pilot capability can be realized through effective utilization of an air-to-air combat simulator.

4. Night Carrier Landing Training in the A-7E

Training effectiveness of the A-7E Night Carrier Landing Trainer (NCLT) was determined by using pilots that were members of the Replacement Air Group (RAG) squadron. The pilot trainees were selected for NCLT training (experimental Group) or NO-NCLT training (control group) on the basis of the following specific selection and assignment criteria:

(a) No previous A-7E experience.

(b) No night carrier landing experience in any aircraft for the last three years.

(c) Random selection from newly designated aviators, pilots who had instructed in the training command but with no fleet experience, pilots who had been assigned to billets with variable flying time for the past 18 months to three years, and ex-prisoners of war or experienced aviators who had not flown in two or three years.

(d) Random selection of pilots on the basis of previous jet flight hours.

From these criteria, 26 pilots were chosen for NCLT training while 27 pilots were placed in the NO-NCLT training group. Their average jet flight hours were 715 and 747 hours respectively [Ref. 84].

The planned simulator training schedule provided for the experimental group to receive 6.5 hours of training with approximately 85 controlled approaches. The control group received 2.5 hours of familiarization training in the simulator but no controlled approaches [Ref. 85].

There were both objective carrier landing performance measures and subjective performance measures used to determine the transfer of training effectiveness. Variables such as altitude and lateral error from glideslope and centerline, an objective measure derived from wire number arrestment, and the percentage of final approaches that resulted in successful landings were some examples of the objective landing performance measurements, while the Landing Signal Officer (LSO) evaluations and pilot questionnaires provided the qualitative performance measurements [Ref. 86].

Both the quantitative and qualitative performance measurements had statistical tests applied to their values. The Night Carrier Qualification Landing Performance Score was significantly different for NCLT pilots (ts = 1.98, df = 46, PV = .02). The night boarding rate was also significantly different for the NCLT pilots based on a t-test of proportions (ts = 1.643, df = 46, PV = .05). The NCLT group (185 approaches) had a 7 percent higher boarding rate than the NO-NCLT group (202 night approaches). The overall attrition rate was found to be significantly different between the two groups (ts = 2.50, df = 51, PV = .006). The NCLT pilots had one disqualification out of 26, while there were eight disqualifications out of the 27 NO-NCLT pilots [Ref. 87]. This means that 96 percent of the NCLT trained pilots were successful in their first carrier qualification period. On the other hand, disqualified pilots averaged 12 weeks longer in training plus they required 19 percent more total A-7E flight hours and 33 percent more night hours before night carrier qualification [Ref. 88]. In terms of qualitative measures, LSO evaluations of final approach and carrier landings were found to be statistically different at night (ts = 2.78, df = 46, PV = .003) [Ref. 89].

It was also determined from analyzing the data that the recently designated aviator received very effective training from the NCLT. His attrition rate was only 8 percent while the new aviator that did not train in the NCLT had an

attrition rate of 44 percent. New aviators, with NCLT training, had a 50 percent success rate for their first night approach compared to a 31 percent success rate for the new aviator with NO-NCLT experience [Ref. 90].

Data, such as described in the preceding paragraphs, support the theory that the NCLT is an effective trainer for preparing aviators for night carrier qualification. From a safety standpoint, the night carrier accident rate has been reduced by 80 percent since introduction of the NCLT into the training process [Ref. 91].

E. SUMMARY

Section IV has described methods of measuring training effectiveness, factors influencing simulator training effectiveness, and training effectiveness realized from military flight simulators. No studies examined by this author would support a finding that flight simulators do not provide effective training; however, improving the system's cost effectiveness requires further examination. Section V will investigate the areas of improving and measuring cost effectiveness of visual flight simulation.

V. COST-EFFECTIVENESS OF MILITARY FLIGHT SIMULATORS

A. GENERAL

In a report recently released by Frost and Sullivan, Incorporated, it was disclosed that spending on flight simulators and training devices by the military, NASA, and civilian markets was projected to total slightly below $7 billion between FY 1981 and FY 1985. The Navy was forecast to emerge as the largest buyer during this period with a projected outlay of $2.44 billion, equating to 35 percent of the total market [Ref. 92]. With the amount of money being invested in flight simulators, it is obvious that these systems have become an integral part of the total weapons system procurement for the military; therefore, it is absolutely critical that the systems be utilized in the most cost-effective manner. Section IV described the training effectiveness of military flight simulators, but it should be noted that the fact that flight simulators are effective for training does not necessarily imply that the systems are worth their cost [Ref. 93].

Section V will: (1) examine a method that has been used by the Navy to measure the cost-effectiveness of flight simulators; (2) describe an application of microeconomic theory that could approximate the optimum mix of training hours

between an aircraft and simulator, and therefore improve cost-effectiveness; (3) outline the cost-effectiveness analysis used by the Army for their AH-1 helicopter flight simulator; (4) describe a model developed by the Analytic Services (ANSER MODEL) for determining the cost-effectiveness of air-crew training devices; and (5) suggest an area that could be studied in order to improve the cost-effectiveness of simulator systems.

B. NAVAL AIR SYSTEMS COMMAND COST-EFFECTIVENESS METHODOLOGY

The Navy conducts a cost-benefit analysis as part of the procedure used to determine whether or not to procure a flight simulator system. The costs associated with the analysis include the capital investment, any cost associated with modifications or updates to the system, annual operations and maintenance costs, and any military construction necessary to "house" or support the system. Benefits include cost savings associated with flight hour substitution, depreciation savings, and the assumed savings associated with accident reduction.

Cost savings are determined by using the following equation:

$$\text{Cost Savings} = (\text{Cost/Flight Hour}) \times (\text{Flight Hour Substitution})$$

Cost per flight hour for each aircraft can be obtained from the Navy Program Factors Manual and includes cost associated

with petroleum-oil-lubricants (POL) cost per hour, organizational and intermediate maintenance per flight hour, component rework, replenishment spares, and engine overhaul. Flight hours substitution is the projected number of hours in a year that can be substituted in the simulator instead of flown in the aircraft.

Information necessary to compute depreciation savings includes aircraft acquisition cost, aircraft service life, the number of aircraft at the base where the simulator is located, and the number of flight hours projected to be flown by an aircraft during the year. Depreciation savings are calculated by using the following equation:

$$\text{Depreciation Savings} = (\text{Depreciation/Aircraft}) \times (\text{Number Aircraft}) \times \left(\frac{\text{Flt. Hour Substitution}}{\text{Flt. Hrs} + \text{Flt. Hrs. Subs.}}\right)$$

The third area measured in order to determine annual benefits is accident reduction. The assumption used to support this measurement is that all pilot error accidents could have been avoided by using flight simulators. An estimated monetary loss for damage to aircraft due to pilot error is determined and then multiplied by the yearly flight hour substitution.

$$\text{Accident Reduction Savings} = \frac{\$\ \text{Loss}}{\text{Flt. Hr.}} \times \text{Flt. Hr. Subs.}$$

Other factors considered in procurement of a simulator system includes the value of a human life and the emergency

training capability which is impossible or unsafe to conduct in the aircraft. Both of these factors are difficult to reduce to monetary quantities [Ref. 94].

Utilizing the cost-benefit methodology, this author performed an analysis using data from the Instrument Flight Simulator Training Division at Williams AFB, Arizona. Depreciation savings was not computed since the aircraft at Williams (T-37 and T-38) had exceeded their service lives, making depreciation zero. It should also be noted that in computing the accident reduction savings, $260,000 was used as a value for a human life [Ref. 95]. The amount shown for initial capital investment also includes modifications and updates. Table V-1 presents the cost-effectiveness analysis. Present values are computed using a 10 percent discount factor as required by Department of Defense Instruction 7041.3, Economic Analysis and Program Evaluation for Resource Management.

During the period FY 78 through FY 80, the net benefit associated with the instrument flight simulators totaled $31,336,796, which means that the system was fully amortized in slightly less than three years. As evidenced by the values in Table V-1, flight hour substitution is the primary benefit realized from flight simulator utilization; however, the substitution hours are "best-guess" subjective estimates and are not objectively determined. The next section will outline a procedure for realizing the optimum mix of simulator and aircraft hours using microeconomic theory as a framework.

TABLE V-1

COST-BENEFIT ANALYSIS FOR INSTRUMENT FLIGHT SIMULATORS

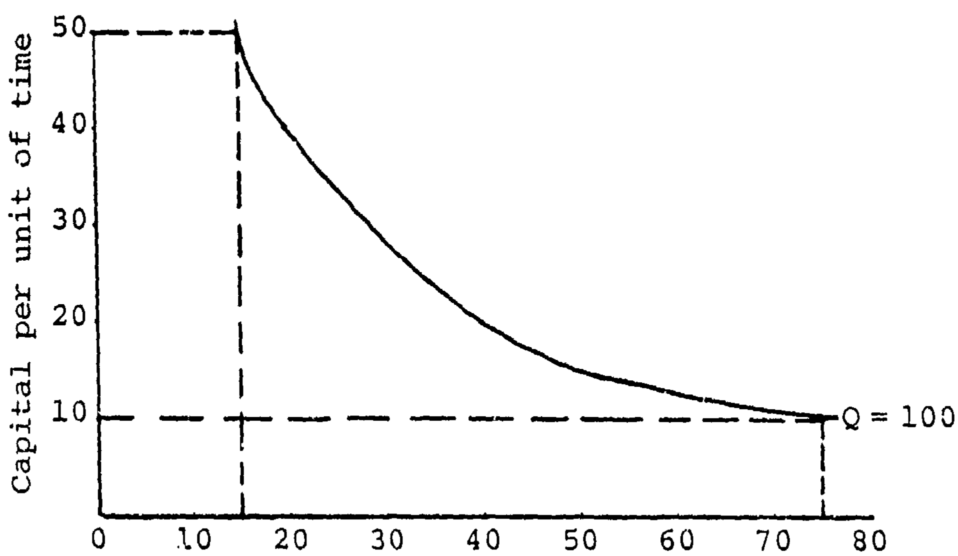
	FY 77	FY 78	FY 79	FY 80
Costs				
Capital Investment	$26,600,000	-0-	-0-	-0-
O&M-Civilian Personnel	-0-	$ 600,000	$ 638,400	$ 677,981
O&M-Military Personnel	-0-	100,000	106,400	112,997
Operating Cost	-0-	109,267	118,002	144,533
Military Construction	4,700,000	-0-	-0-	-0-
Total	31,300,000	809,267	862,802	935,511
Present Value	31,300,000	772,041	748,049	737,183
Benefits				
Flight Hour Substitution	-0-	9,115,640	11,375,165	18,677,288
Accident Reduction	-0-	109,028	108,070	152,371
Total	-0-	9,224,668	11,483,235	18,829,659
Present Value	-0-	8,800,333	9,955,965	14,837,771
Net Benefit	(31,300,000)	8,028,292	9,207,916	14,100,588

C. IMPROVING COST-EFFECTIVENESS USING MICROECONOMIC THEORY AS A FRAMEWORK

The microeconomic theory being used is normally employed when showing production with two variable inputs. An example of variable inputs would be labor and capital. Different combinations of labor and capital can be used to produce the same output. Figure V-1 depicts this by plotting an isoquant on a graph with capital on the y-axis and labor on the x-axis.

FIGURE V-1

PRODUCTION ISOQUANT



The graph shows that different combinations of inputs such as 50 units of capital and 15 units of labor or 10 units of capital and 75 units of labor produce the same 100 units of output; therefore, an isoquant is a curve showing all possible combinations of inputs physically capable of producing a given

level of output. Isoquants are concave from above, indicating a diminishing marginal rate of technical substitution. This concavity implies that as capital decreases by equal amounts, proportionately more labor must be added in order to maintain the same output level [Ref. 96].

With the isoquant plotted, the producer is now concerned with the costs associated with the two inputs. In determining his operating input, it is important for the producer to pay particular attention to relative input prices in order to minimize the cost of producing a given output or maximize output for a given level of cost.

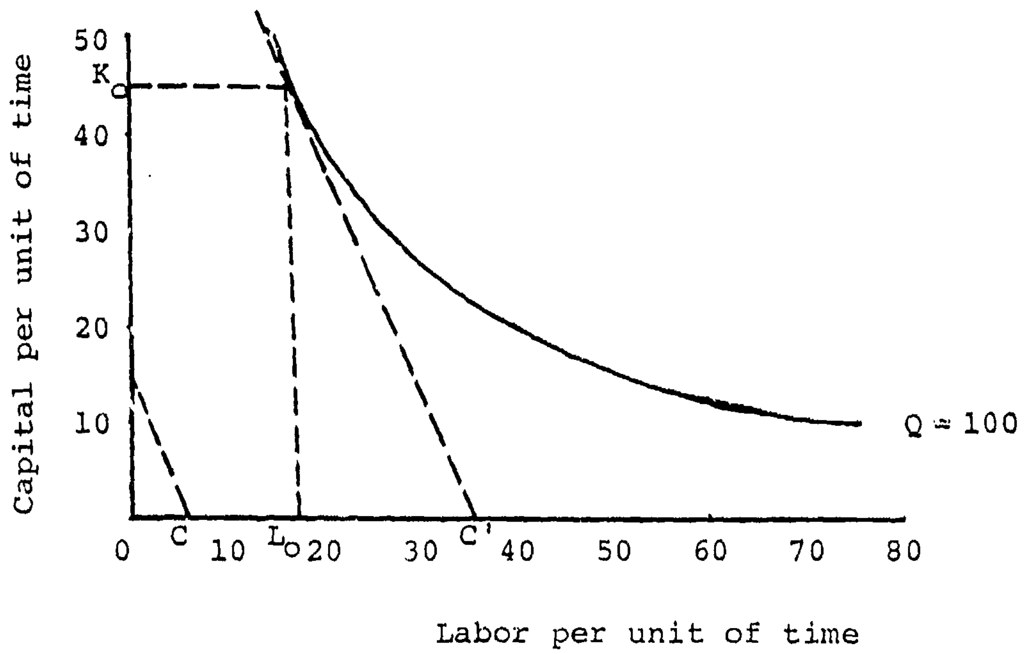
The next step in the analysis would be to plot a cost constraint on a graph such as depicted in Figure V-1. As an example, suppose the cost of capital was $1000 per unit and labor wage rates were $2500 per man year. If the decision was made to invest $15,000 in the two inputs, then the producer could invest the total amount in capital resulting in 15 units being purchased, or he could invest totally in labor allowing him to purchase six man years. Using these two points, the producer could plot the cost constraint, line C on the isoquant graph as depicted in Figure V-2.

The producer would use the combination of inputs where the cost constraint, line C', is tangent to the production isoquant. This satisfies the principle of maximizing output subject to a given cost or minimizing cost subject to a given output because at the tangency point the marginal rate of

technical substitution is equal to the input price ratio (the price of labor to the price of capital). For the producer, the criterion for fixed effectiveness at the minimum cost would be to use K_o units of capital and L_o units of labor [Ref. 97].

FIGURE V-2

PRODUCTION ISOQUANT AND COST CONSTRAINT



This analysis can be applied to the determination of the optimum mix of aircraft hours and simulator hours necessary to attain a required level of effectiveness at the minimum operating cost. In 1973, a study was conducted by Povenmire and Roscoe in which they developed an effectiveness isoquant by plotting the average hours needed for students to pass their final flight check after practicing a certain number

of hours in the Piper Cherokee and the Link GAT-1 trainer. Table V-2 outlines the results of this study [Ref. 98].

TABLE V-2

SIMULATOR HOURS VS. AIRCRAFT HOURS
NEEDED TO PASS FINAL FLIGHT CHECK
(Source: Povenmire and Roscoe, 1973)

Group	Group Size	Average Hours Needed to Pass Final Flight Check
Aircraft only	14	45.4
Simulator		
3 Hours	13	40.3
7 Hours	9	38.6
11 Hours	10	37.9

If one were to plot and connect the four points, the resultant curve would be an effectiveness isoquant because all combinations of aircraft and simulator time result in the student being able to pass his final flight check, i.e., fixed effectiveness. The next step in the procedure would be to determine the operating cost per hour for the aircraft and simulator. By taking these costs and dividing each into some fixed investment dollars, a cost constraint line could be determined. The tangency point between this line and the effectiveness isoquant would show the optimum mix of aircraft hours and simulator hours needed to satisfy the fixed effectiveness at the minimum cost.

D. COST-EFFECTIVENESS ANALYSIS FOR THE AH-1 HELICOPTER

The Army conducted a cost and training effectiveness analysis (CTEA) for the AH-1 "Cobra" flight simulator (AH-1FS) and released it through the Directorate of Training Developments, U.S. Army Aviation Center, Fort Rucker, Alabama, in November 1979.

The cost-effectiveness portion of the study was divided into three major areas, including the task training analysis, the cost analysis, and the task priority.

As with most studies described in this thesis, two groups were designated to undergo the required training with the control group receiving all training in the aircraft and the experimental group completing simulator training before flying the aircraft. All aviators in both groups had completed primary rotary wing training in the UH-1 "Huey" helicopter. The control group was comprised of 14 aviators with an average of 517 rotary wing hours while the experimental group had 26 aviators with an average experience level of 546 rotary wing hours [Ref. 99].

Data were collected for both the experimental and control group for 44 separate tasks. The data forms were identical so that training in the simulator could be compared to training in the aircraft. Examples of tasks to be performed included: hover flight, maximum performance takeoff, running landings, and firing of rockets.

The first step in the study was to det[illegible] the task training analysis. For each of the 44 distinct tasks, a curve was developed showing the relationship between task training in the simulator and the aircraft. The equation for this curve was in the form of $Y = b_1 e^{-b_2 x} + b_3$, where x is defined as the amount of simulator training time and Y is the amount of additional aircraft training time required to meet the standard. The variables b_1, b_2, and b_3, were numerical values determined from a least squares fit to the collected data. The fixed effectiveness utilized was determined by Aviator Qualification Course (AQC) standards for each of the tasks. For the task of running landings, the equation for the curve was $Y = 5.6^{-0.32x} + 2.51$ [Ref. 100].

The curves that were developed for each task were also used to determine the most cost-effective mix of simulator and aircraft training time. Instead of using the graphical approach as previously described, the analysts used calculus to minimize the total cost equation. This equation was in the form of:

$$C_t = C_1 Y + C_2 X$$

where C_t = total task training cost

C_1 = aircraft task training cost per minute

C_2 = simulator task training cost per minute

X = simulator task training time (minutes)

Y = aircraft task training time (minutes).

Substituting $Y = b_1 e^{-b_2 x} + b_3$ into the total cost equation

and taking the derivative of this equation with respect to X, the mix of simulator and aircraft time needed in order to meet the standard at the lowest cost was:

$$X_m = \frac{1}{b_2} \text{LN} \left(\frac{c_1 b_1 b_2}{c_2}\right)$$

$$Y_m = b_1 e^{-b_2 x_m} + b_3$$

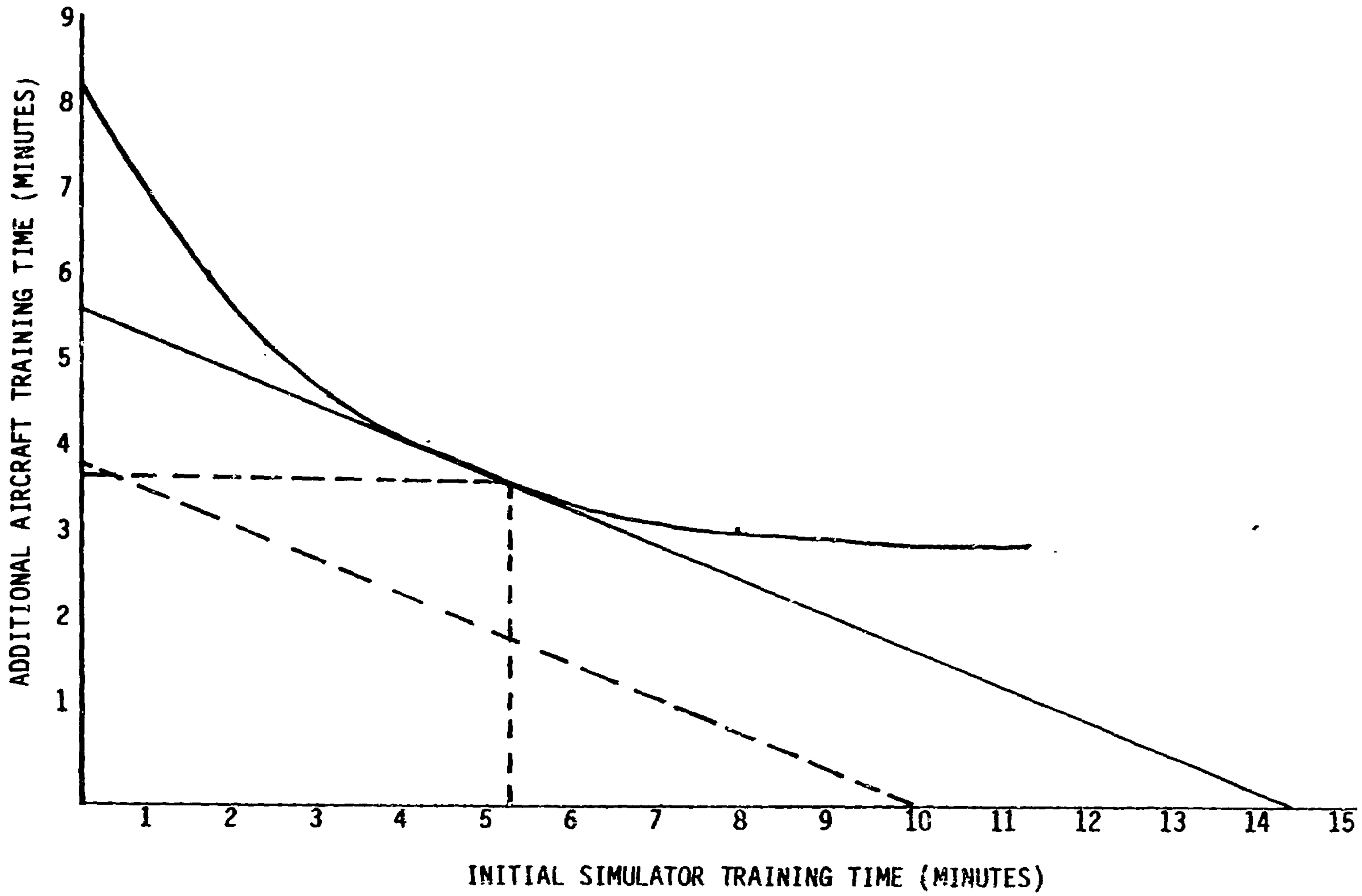
where X_m and Y_m are the simulator and aircraft training times in minutes. These training times were calculated for each of the 44 tasks. In the case of running landings, the optimum mix was calculated to be 5 minutes in the simulator and an additional 4 minutes in the aircraft [Ref. 101].

Once the fixed effectiveness/minimum costs training times were calculated, the cost savings associated with using the simulator and aircraft vice the aircraft only were calculated. In order to determine the cost per minute of the simulator and the aircraft, the percent of time utilized by the device for training the particular task was used as part of the calculation. As an example, the operating and support cost plus the accident cost rate per minute for the AH-1 was \$9.50 (FY 79 dollars). Historical data showed that 73.4 percent of flight time was dedicated to the task training; therefore, the cost per minute would be $\frac{\$9.50}{.734} = \$12.94$. The cost associated with using the simulator was $\frac{\$4.98}{1.00} = \$4.98$. This implied that 100 percent of simulator time was dedicated to task training. From the data, the total cost savings for each task could be calculated [Ref. 102].

After calculating the cost per minute for the simulator ($4.98) and the aircraft ($12.94), this author applied the microeconomic theory previously described to arrive at the optimum mix of device training time at the minimum cost. Figure V-3 shows the effectiveness isoquant ($Y = 5.6e^{-0.32x} + 2.51$) that was developed for running landings with the cost constraint and tangency point showing the respective times. Even with a hand-drawn curve of only five points, the point of tangency indicates slightly more than 5 minutes of simulator time (X_m) and slightly less than 4 minutes of additional aircraft time (Y_m).

The final step in the cost-effectiveness process was to priortize the tasks in order of their dollar savings. Tasks with the highest values were assigned the highest priority. With the priortized list completed, the annual time available to train students on the simulator could be economically allocated. Information such as the number of students expected during the next year and the number of simulator training hours available could be used to calculate the number of hours each student could receive on the device. With the student's training time calculated, one could start adding the simulator minutes as he went down the priortized list until the time was less than or equal to the student's allotment. At that point, the dollar savings associated with each accomplished task could be totaled, giving the cost savings per student.

FIGURE V-3
ISOQUANT AND COST CONSTRAINT FOR AH-1 RUNNING LANDING
(SOURCE: COST AND TRAINING EFFECTIVENESS ANALYSIS OF THE AH-1 FLIGHT SIMULATOR)



The procedure used by the U.S. Army determined the most cost-effective means of employing the flight simulator and aircraft; however, the question of training effectiveness still remained unanswered. To determine this effectiveness, aircraft "checkrides" were given to both groups with scores taken for each of the 44 tasks [Ref. 103]. This author conducted a hypothesis test using the average scores on the "checkrides" with the following results:

$$H_o : \mu_E - \mu_C = 0$$

$$H_1 : \mu_E - \mu_C > 0$$

$$ts = 2.796$$

$$df = 66$$

$$PV = .0034$$

where E = experimental group

C = control group.

Since the PV is less than .01, we may reject the null hypothesis that the population checkride scores are equal and accept the alternative hypothesis that "checkride" scores for the experimental group are greater than "checkride" scores for the control group.

E. THE ANSER MODEL

Presently, economic analyses conducted in conjunction with procurement of flight simulators do not evaluate the effects of variations in training effectiveness. The Air Force has three such models, which are utilized during the simulator acquisition and testing cycle, to include: the

RCA Cost Model, the Logistic Support Cost Model, and the Air Force Test and Evaluation Center (AFTEC) Cost of Ownership Model. All of these models treat training effectiveness as fixed. In other words, the assumption is made that the training alternatives of interest are equally effective; therefore, simple cost comparisons will suffice for cost-effectiveness analysis purposes [Ref. 104].

Cost-effectiveness analysis does not simply mean collecting cost and effectiveness data. A methodology, or a model, must be defined that would simultaneously consider both cost and effectiveness inputs, and allow trade-offs between these inputs in order to efficiently evaluate resource allocation alternatives [Ref. 105]. The cost-effectiveness model must have certain characteristics, to include: (1) a formalized framework so that all alternatives can be compared in a consistent manner; (2) sufficient flexibility to accommodate differences that exist between device training applications; (3) support decisions between various training alternatives on the basis of measured or predicted cost and training effectiveness indices; (4) be sensitive to change with regards to performance, utilization, or capability of the device; (5) include all relevant cost categories associated with training; and (6) be computerized to permit practical application [Ref. 106]. The characteristics described are available within the ANSER model.

The primary purpose of the ANSER model is to identify the most cost-effective mix of training devices (including the aircraft, full-mission simulators, cockpit procedures trainers, part-task trainers, media, and classroom instruction) for aircrew training on a given weapons system. In order to accomplish this purpose, the model requires input data on training requirements and device training capabilities. Once all mixes of devices that can satisfy the training requirements are determined, the model uses device acquisition and operating costs to select the most cost-effective mixes and compute the life cycle costs of these sets of devices [Ref. 107].

The number of training devices from which to make a choice is modeled as a controlled variable while procurement costs and operations and maintenance costs are considered fixed parameters. State variables, such as utilization rates, are dependent upon the controllable variable. By testing all combinations of the integer values of the controllable variables, the most cost-effective combination of devices can be determined [Ref. 108].

Input data for training requirements includes the number of training tasks, the average number of hours required in a device for a student to accomplish each training component, and the number of students to be trained. Data needed for the training device includes the ability of each device to satisfy each training component and the maximum time each

device can be used for training purposes. To determine the ability of a device to satisfy a training component, the task must be evaluated in terms of whether it is transferable or non-transferable. Transferable requirements can be accomplished on a number of different devices, while non-transferable requirements, such as critical emergency procedures training, can only be accomplished on a specific device. This information is very important when trying to allocate the time available on each device [Ref. 109].

For each task, devices are inserted into a matrix in order of increasing capability. Times are then assigned to the devices to meet the total training requirement. The times are assigned first to the least capable device up to its maximum capability. This process is repeated for each device until the complete training requirement is met. If the requirements and capabilities can be successfully meshed, an effective alternative has been determined, therefore applicable cost data can be calculated [Ref. 110]. Figure V-4 provides a simplified schematic for the effectiveness determination.

Input data for training costs includes procurement cost of each training device, operating and support costs for each device, the economic service life for each device, and appropriate discount and inflation factors. Figure V-5 shows the cost process associated with the model.

FIGURE V-4

EFFECTIVENESS DETERMINATION SCHEMATIC
(Source: AFHRL Study TR-79-39)

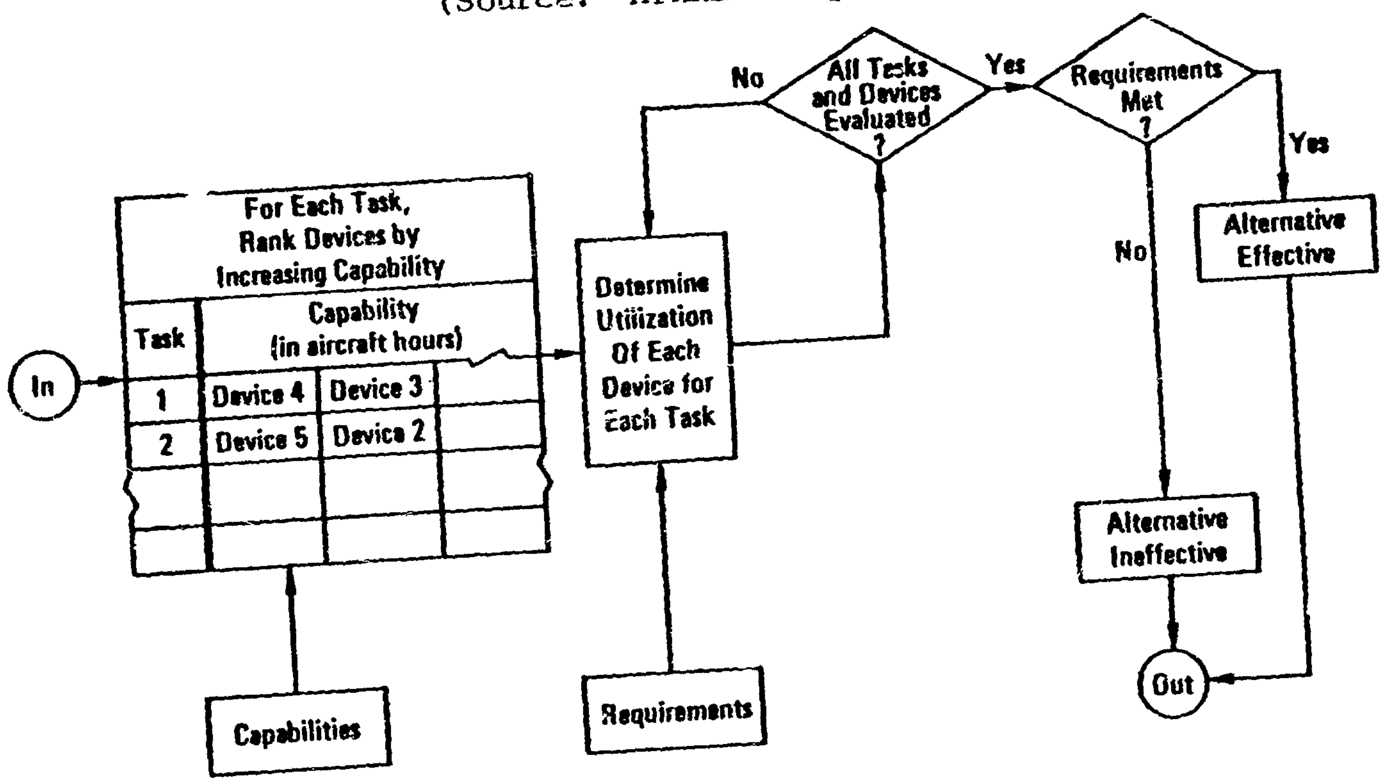
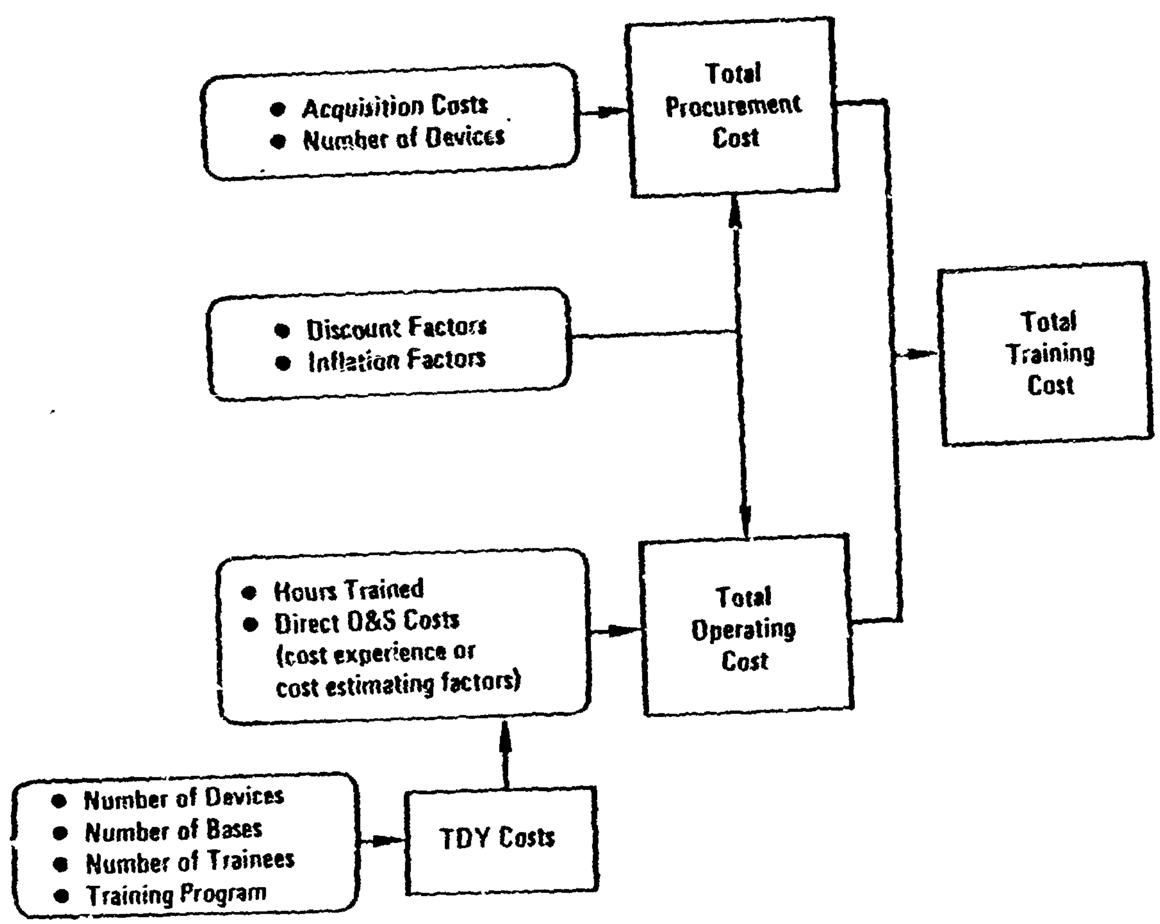


FIGURE V-5

COST PROCESS
(Source: AFHRL Study TR-79-39)



Cost comparisons are based on the average annual cost for each of the effective alternatives. The equation for determining average annual cost is:

$$\text{AVERAGE ANNUAL COST} = \frac{\text{TOTAL PRESENT VALUE}}{\text{SUM OF ANNUAL DISCOUNT AND/OR INFLATION FACTORS}}$$

This equates to the normal present value equation of $P = \frac{Fn}{(1 + r)^n}$, where P = present value, Fn = future value in year n, r = sum of inflation and discount factors, and n = year or period [Ref. 111].

Major cost elements used in the model are,

Acquisition Costs
- Research, Development, Training and Evaluation
- Engineering Development
- Procurement

Operation Costs
- Operations Manpower
- Base System Maintenance Manpower
- Base Maintenance Material
- Miscellaneous Personnel Support
- Utilities/Fuel
- Costs Associated with Temporary Duty

Base Operating Support Costs
- Base Services Manpower
- Miscellaneous Personnel Support

Logistics Support Costs
- Depot Maintenance Manpower and Material
- Supply Depot Manpower and Material
- Second Destination Transportation
- Technical Order Maintenance

Personnel Support Costs
- Recruit Technical Training Manpower
- Technical Training Costs
- Medical Manpower
- Medical Material
- Permanent Change of Station Costs
- Miscellaneous Personnel Support

Recurring Investment Costs
- Replenishment Spares
- Recurring Modifications
- Common Support Equipment [Ref. 112].

Readers of this thesis that are interested in further definitions of each cost element are encouraged to obtain AFHRL Study TR-79-39.

The final output of the model is a readout which provides information on ten effective alternatives. First, it lists the number of each device that is needed to meet the training requirements. Secondly, it shows the investment cost, operations and support costs, annual cost, and cumulative cost for each year of the economic service life. The investment cost and operation and support costs are shown in constant dollars while the annual and cumulative costs are shown in inflated/discounted dollars. Thirdly, a matrix is depicted outlining for each task which device would best meet the training requirements. In other words, it ranks the devices in order of capability. Finally, a matrix is depicted which shows the number of hours that a student should use each training device for each particular task.

Although the ANSER model offers sufficient promise as a true cost-effectiveness model, it does have limitations. The model does not consider the learning curve theory. That is, the model assumes that successive increments in device use are reflected by corresponding increments in training effectiveness. A second limitation is that the model is not

sensitive to significant variations in the input data [Ref. 113]. Presently the Tactical Air Warfare Center at Eglin AFB, Florida is working with the model to correct these limitations. Their results will be of significant importance to any department involved with flight simulator procurement and utilization.

F. THE COST-EFFECTIVENESS OF USING SIMULATORS IN THE PILOT SELECTION PROCESS

In the past, using flight simulators as a step in the screening process for officers to be accepted to undergraduate pilot training has not been of significant importance because of the abundant supply of qualified applicants and the relatively low training costs; however, with the higher fuel costs and the sophistication of current aircraft weapons systems, it is very critical that the personnel that are selected have the highest probability for successful completion of the flight program. Objective data obtained by using a flight simulator could provide early identification of pilot candidates that are likely to attrite and improve the method by which pilots are selected for different aircraft such as fighters, transport, or helicopters.

The Royal Air Force has completed an extensive analysis in using a simulator test as a criterion for pilot selection. After a four-day instruction period in basic instrument flying and use and interpretation of radio navigation aids, the student pilots flew a predetermined route, to include take-off

and climb to altitude, level, climbing, and descending turns, use of navigational aids, and approach to landing. The two main sources of data were the instructor's assessment and objective measures of performance. Correlations of .6 to .8 were obtained between the objective scores and the simulator instructor's assessments. In addition, the biserial correlation of the objective scores with the criterion of pass/fail in flying training was approximately .7 [Ref. 114].

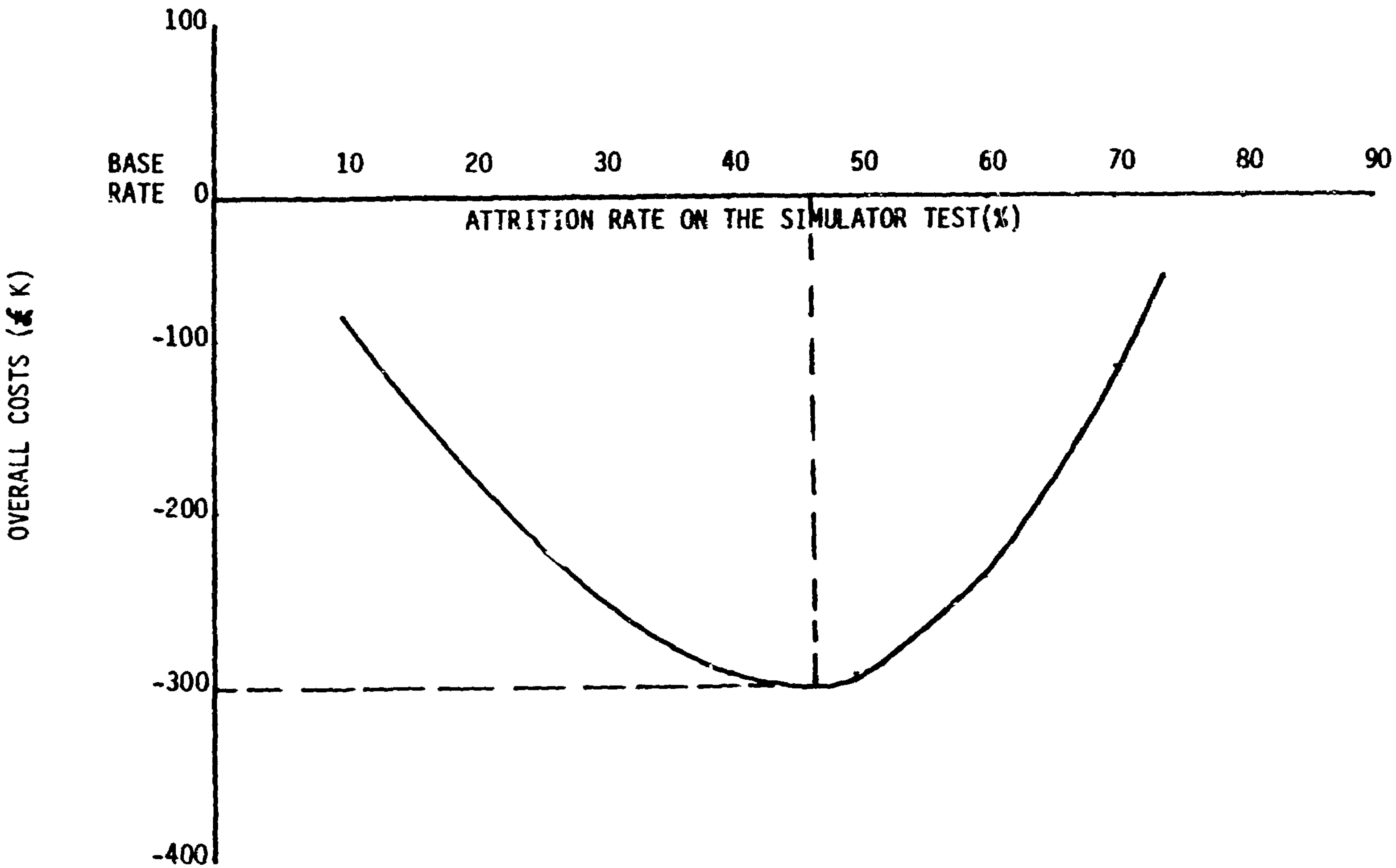
Although the flight simulator in the Royal Air Force analysis was shown to be a good predictor of success or failure in flight training, there were certain costs which accrued in the process. The attrition rate for trainees entering flight school decreased, but the introduction of the simulator into the selection process initiated a new attrition point, that is, the trainees who failed the simulator test. Overall, this could result in a lower number of trainees completing the program, creating manpower shortages for front-line squadrons. In order to overcome this problem, the input must be larger in order to maintain a fixed output. In other words, low attrition rates can be achieved by using simulator testing; however, for a fixed output, the cost savings associated with this reduced attrition may be offset by an increase in recruiting and testing costs [Ref. 115].

There are at least two models which have been developed to assist the decision maker in determining the optimal attrition rate for the simulator. These models are the Recruitment,

Selection, and Training (RESET) cost model developed by L. V. Bennett and H. C. Partridge (1976), and the "CAPER" model developed by W. A. Souls of the Navy Personnel Research and Development Laboratory. By applying realistic cost values to the model, it is possible to calculate: (1) the cost savings resulting from lowered attrition rates and course sizes in training; and (2) the increased costs of selection resulting from larger intake numbers to meet a fixed output [Ref. 116]. Figure V-6 shows the combination of these two costs as a U-shaped function. The lowest point on the curve represents the most cost-effective attrition rate for the simulator selection test. The x-axis represents a base rate which is the cost of selection and training prior to the simulator system, and the Y-axis shows marginal costs from the base rate as a function of the attrition rate. The figure shows that the maximum cost savings is at a point where the simulator attrition rate is 40 percent to 50 percent, resulting in a cost savings of approximately 300,000 British pounds [Ref. 117].

Finally, the Royal Air Force analyzed thoroughly the positioning of the simulator test in the complete training process. It was determined that the most cost-effective point to apply the simulator test was after the existing selection tests as it was the most expensive test to administer. This allowed large numbers of the applicant population to be screened out with lower costs validity tests before using the simulator [Ref. 118].

FIGURE V-6
THE RELATIONSHIP BETWEEN ATTRITION RATE ON THE SIMULATOR TEST
AND OVERALL COSTS OF RECRUITMENT, SELECTION, AND TRAINING
(SOURCE: COLLECTED PAPERS, HUMAN OPERATIONS AND SIMULATION SYMPOSIUM, MARCH,1977)



Within the present aviation selection system used by the Navy, all pilot candidates are selected on the basis of performance in written examinations. The written selection tests include the Academic Qualification Test, Mechanical Comprehension Test, Spatial Apperception Test, and Biographical Inventory. This battery of tests is followed by an extensive flight physical and a preflight school before flight training. This system has been basically unchanged since World War II; however, the Navy is presently evaluating a system entitled the Dynamic Naval Aviation Selection Testing and Evaluation System (DYNASTES). DYNASTES is a battery of five tests which measures performance in the following areas: complex psychomotor coordination, divided attention, selective attention, motion reactivity, and vehicular control. Divided attention using the Integrated Multi-Task Psychomotor and Cognitive Testing System (IMPACT) and vehicular control using the Naval Automated Pilot Aptitude Measurement System (NAPAMS) are completed on a computer system consisting of a PDP-11/34 Central Processing Unit, a VT-11 Graphic Display, an RX02 Duel Floppy Disk, and an Audio Visual Module.

The pass-through Validation is being conducted at the present time with 400 subjects undergoing the testing procedure. Eight students will receive two hours of testing a day for five consecutive days. This process will be repeated every week for 50 weeks. The validation began in October 1980.

It is estimated that the annual cost savings for a 5 percent reduction in attrition (flight hours only) would be $3.0 million. If one considers that the system has a research, development, training, and evaluation cost, plus first-year implementation cost of $1.3 million, this allows amortization within the first year and a resultant savings of $1.7 million.

The importance of the DYNASTES program is effectively emphasized when studying the cost figures associated with Naval Air Training Command attrition rates for FY 79 in Table V-3.

TABLE V-3

NAVAL AIR TRAINING COSTS ASSOCIATED WITH ATTRITION (JET TRAINING)
(Source: Chief of Naval Education and Training, Code N-43A)

Stage	Number of Attrites	Cost per Attrite	Total
Primary Stage	171	$ 36,453.97	$ 6,233,628.87
Basic Stage	43	155,238.37	6,675,249.91
Advanced Stage	28	407,507.40	11,410,207.20
		TOTAL COST -	$24,319,085.98

[Ref. 119]

G. SUMMARY

Section V has outlined different methods used by the military services to measure cost-effectiveness of flight simulators. Of particular importance was the method by which microeconomic theory could be used to determine the optimum

mix of time that should be spent in the airplane and simulator in order to attain a fixed level of effectiveness at the lowest cost.

Section V also described the results of an analysis conducted by the Royal Air Force when using flight simulators as a screening point in its pilot selection process.

Finally, Section V described a program which is currently undergoing evaluation by the U.S. Navy to reduce the student pilot attrition rate by having the trainee complete a more demanding screening process to include measuring his or her ability in operating a simplified flight simulator.

Section VI will discuss this author's conclusions and recommendations concerning the training effectiveness and cost-effectiveness of military flight simulators.

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The purpose of this thesis was to conduct research in the area of visual flight simulation and determine whether or not systems that exist provide both training and cost effectiveness.

Section II provided an overview of flight simulation to include the historical development of flight simulation, a description of visual flight simulation methodology such as model boards, computer generated imagery, and computer animated photographic terrain view, and a description of military flight simulators that are presently being used in the training syllabi for Air Force and Navy aircraft.

Section III examined the use of flight simulators within the commercial aviation industry. Methods by which the major airline companies used the systems to provide training effectiveness were outlined, as well as cost savings realized by major carriers such as American and Delta Airlines. A major point disclosed in Section III was the improvement in standardization of training and economies of scale gained by the airlines centralizing their respective training centers.

Section IV evaluated the effectiveness of simulator systems in training military pilots. It outlined factors such as design of simulator systems, training programs, personnel,

and expectations, discussing how each factor could effect the implementation of simulator systems into the military training concept. Hypothesis testing was completed on data that were gathered from air-to-ground training, air-to-air training, and night carrier landing training. All studies examined supported the fact that flight simulators did provide effective training.

Finally, Section V discussed the cost-effectiveness of military flight simulators. A cost-benefit analysis used by the Navy in the procurement process was applied to Air Force cost data with the result being that investment costs were amortized in slightly less than three years. Microeconomic theory was applied in determining the optimum mix of training hours between the airplane and simulator that could be utilized in meeting a predetermined fixed effectiveness at the minimum cost. A CTEA analysis conducted by the Army for the AH-1 "Cobra" helicopter was outlined using task training analysis, cost analysis, and task priority. The model developed by Analytic Services (ANSER MODEL) to determine cost-effectiveness of aircrew training devices was described with the important point being made that aircrew training devices included the aircraft, simulators, media, and classroom instruction. The model used input data of training requirements, device training capabilities, and pertinent costs to determine the optimum mix of training devices to meet the training requirements. The model would provide ten effective alternatives with their respective life-cycle costs.

The last part of Section V explained an analysis conducted by the Royal Air Force to use flight simulators in the process of selecting personnel for pilot training, and a procedure, DYNASTES, which is currently being validated by the Navy in their pilot selection process. A figure was used to depict the possible cost-tradeoffs of using a simulator in the selection process, pointing out the importance of an accurate attrition rate from the simulator test in order to preclude the possibility of having the input costs, such as recruitment and selection, be greater than the cost savings of training fewer pilots in the aircraft.

B. CONCLUSIONS

1. Flight Simulators Improve Training Effectiveness

This thesis has determined that flight simulators can improve the training effectiveness of military pilots. The major problem is convincing the pilot that the system will not be used as a substitute for actual aircraft time. Even though state-of-the-art technology provides accurate "realism," the typical military pilot needs that valuable time in the aircraft to perfect his flying techniques, thereby increasing the probability of success in an engagement with the enemy. There must be a minimum monthly flight hour requirement set for military pilots so that his or her flying ability can be maintained. Even though the cost associated with this minimum flight time can be quite significant, by

using flight simulation in the training process to practice a particular maneuver or whatever task is required, the pilot is able to use the actual aircraft time more effectively.

2. <u>Flight Simulators Can Increase Long-Run Cost Savings</u>

It is this author's opinion that short-run cost savings associated with flight time substitution has been the key factor in determining whether or not funds are authorized for flight simulator procurement. Using the simulator to practice air-to-ground ordnance delivery or firing air-to-air missiles can result in a long-run cost savings because the pilots would not require as much practice ordnance in order to attain a certain level of effectiveness. More importantly, there can be a greater cost savings associated with accident reduction as a result of the simulator/aircraft training combination because this process has been shown to produce better qualified aviators.

3. <u>The Cost-Effectiveness of Flight Simulation Can Be Improved</u>

Determining the least cost mix of aircraft and simulator time in order to attain a predetermined effectiveness can significantly improve the cost-effectiveness of the system. Objective data can develop both the effectiveness isoquants and the cost constraints, allowing the user of the system to apply the microeconomic theory that was outlined in this thesis.

4. All Levels of Command Must Understand and Support the Flight Simulation System

This conclusion is of primary importance, especially for the fleet user. Nothing is more detrimental to the training process than to have an instructor not understand the capabilities and/or limitations of the system or not believe the system can improve the trainee's ability. It is imperative that flight simulation be eagerly accepted as an integral part of the training process; otherwise, utilization rates will be low and costs will be high.

C. RECOMMENDATIONS

Since the Marine Corps is on the threshold of procuring sophisticated flight simulators for both the F/A-18 and the AV-8B, it is recommended that careful study be given to the following areas of this thesis:

1. The factors influencing training effectiveness outlined in Section IV. It is imperative that training syllabi be developed that allow an interface between the simulator and the aircraft, and that the personnel operating the console of the simulator be professionally trained so that the systems can function at maximum capability.

2. The hypothesis testing completed in Section IV which supported the fact that flight simulators can provide excellent training in different flying environments.

3. The microeconomic theory in Section V which could be applied to pilots using the F/A-18 and AV-8B, allowing

effectiveness isoquants to be developed for all tasks that could be learned in either the simulator or the aircraft.

4. The ANSER MODEL, outlined in Section V, to determine whether or not it can be utilized by the Marine Corps in future weapons systems procurement.

APPENDIX A

SIMULATOR AND VISUAL SYSTEM REQUIREMENTS

a. Discussion. For the convenience of the reader, the simulator and visual system requirements of Appendix H to Part 121 have been included in this appendix. Clarification has been included for some requirements. The preamble to the Advanced Simulation Rule contains additional guidance regarding these requirements.

b. Simulator Requirements - General.

(1) The cockpit should represent a full-scale mockup of the aircraft simulated. Where movement of controls and switches is involved, the direction of movement should be identical to that in the applicant's aircraft.

(2) Circuit breakers that affect procedures and functions resulting in observable cockpit indications should be functionally accurate.

(3) The effect of aerodynamic changes for various combinations of drag and thrust normally encountered in flight should correspond to actual flight conditions. The effect of change in aircraft attitude, thrust, drag, altitude, temperature, gross weight, center of gravity location, and configuration should be included.

(4) All relevant instrument indications involved in the simulation of the applicable aircraft should be entirely automatic in response to control movement by a crewmember.

(5) The rate of change of simulator instrument readings and of control forces should correspond to the rate of change which would occur on the applicable aircraft under actual flight conditions for any given change in forces applied to the controls, in the applied power, or in aircraft configurations.

(6) Control forces and degree of actuation control travel should correspond to that which would occur in the aircraft under actual flight conditions.

(7) Communications and navigation equipment should correspond to that installed in the applicant's aircraft and should operate within the tolerances prescribed for the actual airborne equipment. Long range navigation systems should be

installed but need not be operative unless required by Part 121, Appendix H.

(8) In addition to the flight crewmember stations, there should be two suitable seat accommodations for the Instructor/Check Airman and FAA Inspector. Operators who have the Check Airman/Instructor occupy a flightcrew position seat need only provide one additional observer seat. These seats should provide adequate vision to the pilot's panel and forward windows in visual system models. Observer seats need not represent the aircraft seats.

(9) Simulator systems should simulate the applicable aircraft system operation, both on the ground and in flight. Major systems should be operative to the extent that normal operating procedures, and abnormal and emergency procedures included in the operator's programs can be accomplished.

(10) An Instructor Control Console should be installed to enable the Instructor/Check Airman or FAA Inspector (when applicable) to control the visual attachment (if installed) and insert abnormal or emergency conditions into the aircraft systems.

c. Visual Requirements - General.

(1) The visual scene should accurately portray the environment equivalent to that which the pilot observes on the related simulator cockpit instrument display resulting from the manipulation of the controls and the effects of varying wind conditions.

(2) The visual display may be either a monoview or duoview display. If a monoview display is used, it should be capable of transfer of display at either pilot station.

(3) The scene should comprise the airfield, surrounding area, airport ramp and taxiway.

(4) Representations of buildings or other outstanding features should be suitably detailed to produce a realistic effect on picture presentation.

(5) Functional airfield and approach lighting should be representative of the runway depicted with intensity controls to vary degree of lightness. Approach and runway, and lighting intensities should be independently variable. Realistic colors for approach, and runway lighting are required. Computer-generated image (CGI) systems should have the capability of portraying runway texture or surface.

(6) The aircraft landing lights should be operational.

(7) The optical system for Phase I and less sophisticated simulators should be capable of providing at least a 45° field of vision. Focus should be automatic in order to keep at optimum that part of the picture which is significant to the pilot. A minimum of 75° horizontally and 30° vertically is required for Phase II and III visual systems.

(8) An instructor's control should be provided to allow control of all aspects of the visual system; i.e., cloudbase, visibility in miles and feet, airport selection, environmental lighting controls, VASI, etc.

(9) Visual systems approved for instrument takeoffs and/or instrument approach procedures should have a means of reducing visibility to reasonably simulate the appropriate weather conditions.

(10) Operators possessing visual systems that do not meet all the requirements contained in this paragraph and have received prior approval will have "grandfather rights." These systems will be eligible for continued approval for all maneuvers originally approved provided they are maintained to the level of acceptability demonstrated at original approval. The "grandfather rights" apply only to the original operator and are not transferable.

d. Simulator Requirements - Phase I.

(1) Aerodynamic programming to include:

(a) Ground effect--for example, roundout, flare, and touchdown. This requires data on lift, drag, and pitching moment in ground effect.

(b) Ground reaction--reaction of the airplane upon contact with the runway during landing to include strut deflections, tire friction, and side forces.

(c) Ground handling characteristics--steering inputs to include crosswind, braking, thrust reversing, deceleration, and turning radius.

(2) Minimum of 3-axis freedom of motion systems.

(3) Phase I landing maneuver test guide to verify simulator data with actual airplane flight test data, and provide simulator performance tests for initial approval.

(4) Multichannel recorders capable of recording Phase I performance tests.

e. Visual Requirements - Phase I.

(1) Visual system compatibility with aerodynamic programming.

(2) Visual system response time from pilot control input to visual system output shall not exceed 300 milliseconds more than the movement of the airplane to a similar input. Visual system response time is defined as the completion of the visual display scan of the first video field containing different information resulting from an abrupt control input.

(3) A means of recording the visual response time for comparison with airplane data.

(4) Visual cues to assess sink rate and depth perception during landings.

(5) Visual scene to instrument correlation to preclude perceptible lags.

f. Simulator Requirements - Phase II.

(1) Representative crosswind and three-dimensional windshear dynamics based on airplane related data.

(2) Representative stopping and directional control forces for at least the following runway conditions based on airplane related data:

(a) Dry.

(b) Wet.

(c) Icy.

(d) Patchy wet.

(e) Patchy icy.

(f) Wet on rubber residue in touchdown zone.

(3) Representative brake and tire failure dynamics (including antiskid) and decreased brake efficiency due to high brake temperatures based on airplane related data. These representations should be realistic enough to cause pilot identification of the problem and implementation of appropriate procedures. Simulator pitch, side loading and directional control characteristics should be representative of the aircraft.

(4) A motion system which provides motion cues equal to or better than those provided by a six-axis freedom of motion system.

(5) Operational principal navigation systems, including electronic flight instrument systems, INS, and OMEGA, if applicable. This requirement is to enhance LOFT; therefore, if the operator's route structure requires dual long range navigation systems on board its aircraft (i.e., Omega, INS, Doppler) a sufficient number of simulators, but in no case less than one simulator, should be equipped with the appropriate long-range navigation system utilized.

(6) Means for quickly and effectively testing simulator programming and hardware. This could include an automated system which could be used for conducting at least a portion of the tests in the ATG.

(7) Expanded simulator computer capacity, accuracy, resolution, and dynamic response to meet Phase II demands. Resolution equivalent to that of at least a 32-bit word length computer is required for critical aerodynamic programs.

(8) Timely permanent update of simulator hardware and programming subsequent to airplane modification.

(9) Sound of precipation and significant airplane noises perceptible to the pilot during normal operations and the sound of a crash when the simulator is landed in excess of landing gear limitations. Significant airplane noises should include noises such as engine noise, flap, gear and spoiler extension and retraction and thrust reversal to a comparable level as that found in the aircraft.

(10) Aircraft control feel dynamics shall duplicate the airplane simulated. This shall be determined by comparing a recording of the control feel dynamics of the simulator to airplane measurements in the takeoff, cruise, and landing configuration. Airplane measurements may be obtained on the ground if proper pitot static inputs are provided to represent airspeeds typical of those encountered on takeoff, cruise and landing. This should provide control feel measurements comparable to those encountered in flight.

(11) Relative responses of the motion system, visual system, and cockpit instruments shall be coupled closely to provide integrated sensory cues. These systems shall respond to abrupt pitch, roll, and yaw inputs at the pilot's position within 150 milliseconds of the time, but not before the time, when the airplane would respond under the same conditions.

Visual scene changes from steady state disturbance shall not occur before the resultant motion onset but within the system dynamic response tolerance of 150 milliseconds. The test to determine compliance with these requirements shall include simultaneously recording the analog output from the pilot's control column and rudders, the output from an accelerometer attached to the motion system platform located at an acceptable location near the pilots' seats, the output signal to the visual system display (including visual system analog delays), and the output signal to the pilot's attitude indicator or an equivalent test approved by the Administrator. The test results in a comparison of a recording of the simulator's response to actual airplane response data in the takeoff, cruise, and landing configuration.

g. <u>Visual Requirements - Phase II</u>.

(1) Dusk and night visual scenes with at least three specific airport representations, including a capability of at least 10 levels of occulting, general terrain characteristics, and significant landmarks. It is not necessary for each airport scene to contain 10 levels of occulting but there should be a means of demonstrating that the visual system has that capability.

(2) Radio navigation aids properly oriented to the airport runway layout.

(3) Test procedures to quickly confirm visual system color, RVR, focus, intensity, level horizon, and attitude as compared to the simulator attitude indicator.

(4) For the approach and landing phase of flight, at and below an altitude of 2,000 feet height above the airport (HAA) and within a radius of 10 miles from the airport, weather representations including the following:

(a) Variable cloud density.

(b) Partial obscuration of ground scenes; that is, the effect of a scattered to broken cloud deck.

(c) Gradual break out.

(d) Patchy fog.

(e) The effect of fog on airport lighting.

(f) Category II and III weather conditions. These representations are required only if the operator is authorized to operate under Category II or III conditions.

(5) Continuous minimum visual field of view of 75° horizontal and 30° vertical per pilot seat. Visual gaps shall occur only as they would in the airplane simulated or as required by visual system hardware. Both pilot seat visual systems shall be able to be operated simultaneously.

(6) Capability to present ground and air hazards such as another airplane crossing the active runway or converging airborne traffic.

h. Simulator Requirements - Phase III.

(1) Characteristic buffet motions that result from operation of the airplane (for example, high-speed buffet, extended landing gear, flaps, nose-wheel scuffing, stall) which can be sensed at the flight deck. The simulator must be programmed and instrumented in such a manner that the characteristic buffet modes can be measured and compared to airplane data. Airplane data are also required to define flight deck motions when the airplane is subjected to atmospheric disturbances such as rough air and cobblestone turbulence. General purpose disturbance models that approximate demonstrable flight test data are acceptable.

(2) Aerodynamic modeling for aircraft for which an original type certificate is issued after June 1, 1980, including low-altitude, level-flight ground effect, mach effect at high altitude, effects of airframe icing, normal and reverse dynamic thrust effect on control surfaces, aeroelastic representations, and representations of nonlinearities due to side slip based on airplane flight test data provided by the manufacturer.

(3) Realistic amplitude and frequency of cockpit noises and sounds, including precipitation static and engine and airframe sounds. The sounds shall be coordinated with the weather representations required in Phase III visual requirement No. 3.

(4) Self-testing for simulator hardware and programming to determine compliance with Phase I, II, and III simulator requirements.

(5) Diagnostic analysis printout of simulator malfunctions sufficient to determine MEL compliance. These printouts shall be retained by the operator between recurring FAA simulator evaluations as part of the daily discrepancy log required under 121.407(a)(5).

i. Visual Requirements - Phase III.

(1) Daylight, dusk, and night visual scenes with sufficient scene content to recognize a specific airport, the terrain, and major landmarks around that airport and to successfully accomplish a visual landing. The daylight visual scene must be part of a total daylight cockpit environment which at least represents the amount of light in the cockpit on an overcast day. For the purpose of this rule, daylight visual system is defined as a visual system capable of producing, as a minimum, full color presentations, scene content comparable in detail to that produced by 4,000 edges or 1,000 surfaces for daylight and 4,000 light points for night and dusk scenes, 6-foot lamberts of light at the pilot's eye (highlight brightness), 3-arc minutes resolution for the field of view at the pilot's eye, and a display which is free of apparent quantization and other distracting visual effects while the simulator is in motion. The simulation of cockpit ambient lighting shall be dynamically consistent with the visual scene displayed. For daylight scenes, such ambient lighting shall neither "washout" the displayed visual scene nor fall below 5-foot lamberts of light as reflected from an approach plate at knee height at the pilot's station and/or 2-foot lamberts of light as reflected from the pilot's face.

(2) Visual scenes portraying representative physical relationships which are known to cause landing illusions in some pilots, including short runway, landing over water, runway gradient, visual topographic features, and rising terrain.

(3) Special weather representations which include the sound, visual, and motion effects of entering light, medium, and heavy precipitation near a thunderstorm on takeoff, approach, and landings at and below an altitude of 2,000 feet HAA and within a radius of 10 miles from the airport.

(4) Phase II visual requirements in daylight as well as dusk and night representations.

(5) Wet and, if appropriate for the operator, snow-covered runway representations, including runway lighting effects.

(6) Realistic color and directionality of airport lighting.

(7) Weather radar presentations in aircraft where radar information is presented on the pilot's navigation instruments.

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